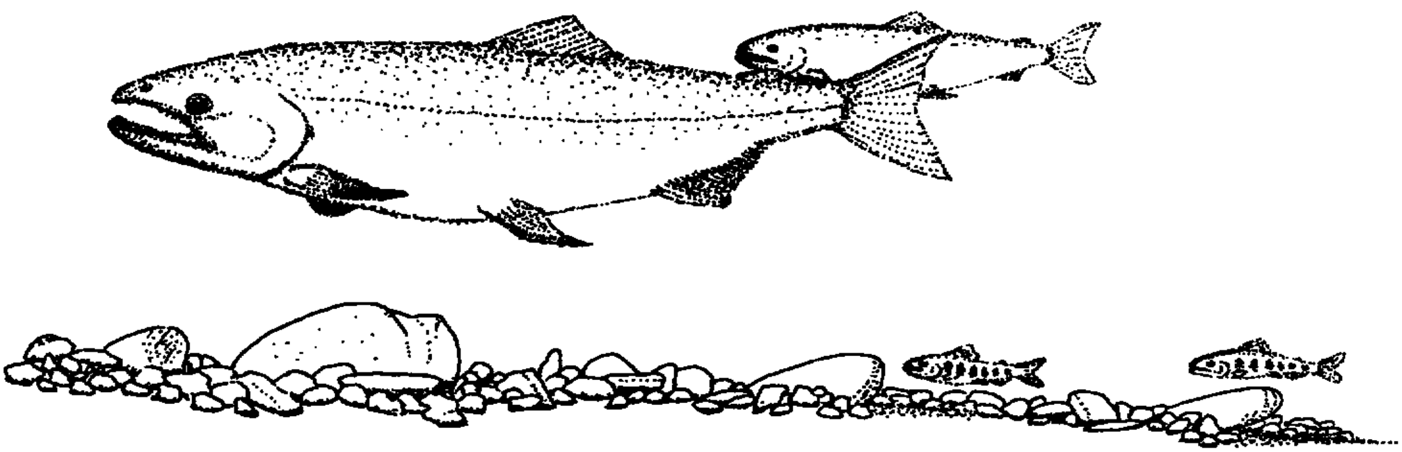
U.S. DEPARTMENT OF THE INTERIOR

FISH AND WILDLIFE SERVICE

PREDATION ON SOCKEYE SALMON FRY BY COTTIDS AND OTHER PREDATORY FISHES IN THE LOWER CEDAR RIVER, 1996



WESTERN WASHINGTON FISHERY RESOURCE OFFICE

OLYMPIA, WASHINGTON

NOVEMBER 1996

PREDATION ON SOCKEYE SALMON FRY BY COTTIDS AND OTHER PREDATORY FISHES IN THE LOWER CEDAR RIVER, 1996

Roger Tabor

and

Jeff Chan

U.S. Fish & Wildlife Service
Western Washington Fishery Resource Office
Olympia, Washington

November 1996

ABSTRACT

An inventory of cottids and other piscivorous fishes was conducted in the lower 1.7 km of the Cedar River to estimate predation on sockeye salmon fry (*Oncorhynchus nerka*) during their emigration to Lake Washington. The 1996 effort completed the final phase of a two-year plan developed to study these predation levels. Efforts focused on cottid species, after the initial year of the study indicated prickly sculpin (*Cottus asper*) were a major predator on salmonid fry and were potentially the most abundant species in the lower Cedar River. Three additional species of cottid (coastrange sculpin (*C. aleuticus*), reticulate sculpin (*C. perplexus*) and torrent sculpin (*C. rhotheus*)) were found to inhabit the lower river. Habitat use by predators, especially cottids, appears to be highly influenced by water depth and velocity. Other factors such as inter and intraspecific competition and predation may also be important in distribution. Results indicate prickly and torrent sculpin consumed the greatest number of salmonid fry, while coastrange and reticulate sculpin consumed few fry. Prickly sculpin, which inhabited the deep, low velocity sections of the lower Cedar River, were found to be the most abundant predator. During their emigration to Lake Washington, sockeye salmon fry are also vulnerable to predation by several other species of piscivorous fish. Cutthroat trout (*O. clarki*) and coho salmon (*O. kisutch*) appeared to be major predators of salmonid fry in the lower Cedar River in 1996, whereas rainbow trout/steelhead (*O. mykiss*) consumed few fry. Results indicate abundance of predatory salmonids was markedly lower compared to the first year (1995) of the study, potentially as a result of record winter flooding. Smallmouth bass (*Micropterus dolomieui*), yellow perch (*Perca flavescens*) and brown bullhead (*Ictalurus nebulosus*) were also present, but not abundant and did not consume any salmonid fry.

Results indicated that a large-scale dredging project which would deepen the channel and reduce water velocities in some areas would probably create additional foraging sites for piscivorous fishes, particularly prickly sculpin, and may increase overall predation on sockeye salmon fry emigrating to Lake Washington. However, the degree of this impact may be influenced by other factors such as discharge and turbidity, as well as densities of sockeye salmon fry and alternative prey.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Predation of emigrating juvenile salmonids by other fishes can be a significant source of mortality (Hunter 1959; Foerster 1968; Rieman et al. 1991). Although sockeye salmon (*Oncorhynchus nerka*) fry reduce their vulnerability to predators by migrating at night, predation rates can still be quite high. For example, Foerster (1968) estimated that losses to predatory fishes ranged from 63-84% over a four-year period. Sockeye salmon fry emigrating through the lower Cedar River are vulnerable to predation by several species of piscivorous fish.

Results of 1995 sampling in the lower Cedar River indicated that the prickly sculpin (*Cottus asper*) was an important predator of sockeye salmon fry (Tabor and Chan 1996). However, no density or population estimates were done. In addition, we did not examine the diet of prickly sculpin < 90 mm total length (TL) and little work was done on other species of cottids. In laboratory experiments and other artificial situations, cottids have been shown to readily feed on juvenile salmonids (Clary 1972; Patten 1971a). However, under most natural conditions, predation on salmonids by cottids is rare (Moyle 1977, Fresh and Schroder 1987). Cottids appear to feed on salmonids in some situations such as during large emigrations of salmonid fry (Hunter 1959; Foerster 1968) or during early stream rearing of salmonids (Patten 1962; Hillman 1989). Hunter (1959) estimated that cottids consumed from 10-28% of emigrating pink salmon fry. The apparent large population of prickly sculpin and observed predation on sockeye salmon fry indicated that further work was needed to assess their overall impact on sockeye salmon fry survival.

Much of the predation by prickly sculpin that we noted in 1995 occurred shortly after a hatchery release of 383,000 sockeye salmon fry (Tabor and Chan 1996). Foerster (1968) reported that after a hatchery release of sockeye salmon fry, one cottid was collected that contained 111 fry. Following the release of hatchery chinook salmon fry (*O. tschawytscha*), prickly sculpin contained an average of 0.6 fry per stomach (Patten 1971b). Prickly sculpin appear to be an important predator of sockeye salmon fry when fry are present in large numbers, such as after a hatchery release.

The Cedar River is subject to occasional flooding during peak winter flow events. Much of the flood damage occurs in the lower 1.7 km. Average annual flood damages in the lower river have been estimated at $670,000. Recently the U.S. Army Corps of Engineers and the City of Renton developed several alternatives for flood control. Alternatives included some level of dredging within the lower 1.7 km and construction of certain levees.

One possible effect of any flood control measure in the Cedar River is a shift in fish distribution, abundance, and species composition. Because many of the fish species are potential piscivores, shifts in these fishes may have important effects on prey fish populations. Modifications such as dredging that change the river channel may reduce water velocities in some areas and cause sockeye salmon fry to be more vulnerable to predators.

The objectives of this study were to: 1) conduct an inventory of cottids and other predatory fishes in the lower 1.7 km of the Cedar River, 2) estimate consumption of sockeye salmon fry by predatory fishes, and 3) evaluate the potential effects of Cedar River flood control projects on predation of sockeye fry.

STUDY SITE

The study site was the lower 1.7 km of the Cedar River (Figure 1). The Cedar River is the main tributary for the Lake Washington basin. The river originates at approximately 1,220 m elevation and over its 80-km course falls 1,180 m. The lower 35.1 km are accessible to anadromous salmonids. Landsburg Dam (Figure 1), a water diversion structure, prevents fish from migrating further upstream.

During normal flows, much of the lower section (0-400 m) of the lower Cedar River is slow velocity water that is backed up from Lake Washington (Figure 2,3). The amount of backed-up water varies depending on lake level and discharge. During winter (December to February) the lake level is kept low at an elevation of 6.1 m. Starting in late February the lake level is slowly raised to 6.6 m by May 1 and 6.7 m by June 1. The shoreline of the lower 600 m of river consists of steep banks, which are armored or stabilized by wooden structures (bulkheads), riprap, and gabions in many areas. Much of the middle section between 400 and 700 m is a transition zone with moderate water velocities depending on the discharge and lake level. During winter, riffle and glide habitat is present; however, as the lake level rises this reach becomes mostly glide and pool-like habitat.

The upper section of the lower Cedar River (700-1,700 m) is characterized by mostly shallow riffle habitat with moderate-to-high water velocities (Figure 3). The only slow water or pool-type habitats are some small backwaters along the shores, a backwater pool under the upper Boeing Bridge, and a side channel immediately downstream of the upper Boeing Bridge. Most of the left bank shoreline is armored with riprap.

Two large flood events (> 200 m^3/s; Wiggins et al. 1996; USGS unpublished data) during winter 1995-96 had altered stream characteristics within many of the previous year's sampling transects. In general, transects had to be remeasured to adjust for new areas of bed scour and deposition along shorelines. Deposition had the largest impact on the study site, enlarging many of the backpack electrofishing transects and reducing or eliminating boat electrofishing transects. An increase in woody debris deposits had also occurred in some sampling areas. The location of beach seine sites did not vary appreciably from the previous sampling year; however, depth and/or bottom type changed at all three sites.

METHODS

Cottids and other piscivorous fishes were sampled in the lower 1.7 km of Cedar River during the emigration period of sockeye salmon fry (February - June). Both electrofishing and beach seining equipment were used to sample predators. Sampling dates in February and March were selected to coincide with hatchery releases of salmon fry (Figure 4). Before we began sampling each day we allowed enough time for most of the hatchery fry to pass through the study reach. Passage time estimates were determined by D. Seiler (WDFW, personal communication) from prior fry trap catches. From April to June, we electrofished every one to two weeks. Due to time constraints and the lack of personnel, we sampled with the beach seine once during March and again in June. The March sample was selected to coincide with a hatchery release.

We assumed that cottids < 60 mm TL were not piscivorous and were not included in most analyses. In other studies, where large cottids had consumed prey fish, cottids < 60 mm TL were rarely piscivorous (Northcote 1954; Patten 1971b; Rickard 1980; Hillman 1989). During electroshocking, we generally netted all cottids ≥ 55 mm TL; however, cottids 55-59 mm TL were discarded. During beach seining, we also examined cottids 50-59 mm TL to collect some preliminary data on their diet.

Beach Seining.-- Predatory fishes were collected at three sites in the lower Cedar River. We used a 30-m-long beach seine with a maximum depth of 2 m in the wings and 2.4 m in the middle (bag). The wings were made of 20-mm stretch mesh and the bag was made of 6-mm stretch mesh.

A beach seine was utilized to sample the center of the river channel, although we attempted to set as close as possible to the channel margins. We only identified three suitable beach seining sites in lower Cedar River because of high water velocities and the presence of instream structures. All three sites were in the lower 700 m (lower and middle sections) of the study reach (Table 1, Figure 2). Generally, water velocities were slower at site 1, the lowest site, than at the other two sites. Each site was sampled one to three times after dark. The net was deployed from a small inflatable raft.

Electrofishing.-- We sampled with a 6-m Smith-Root electrofishing boat and a Smith-Root model 12 backpack electrofisher. We used 60-Hz pulsed direct current to shock fish with the boat electrofisher. Percent output was adjusted to deliver 4-5 amps of electricity to the water. We used 30-Hz pulsed direct current to shock fish with the backpack electrofisher. Output voltage range was set at 300-V.

Five lower section transects (one backpack and four boat) of varying length were established (Table 1). We made one pass along the shoreline of each transect except at the lower Boeing Bridge transects, where the entire channel width was sampled. All sampling occurred at night, beginning at least one hour after dark.

The middle and upper sections of the lower Cedar River, which were too shallow for the electrofishing boat, were sampled exclusively with a backpack electrofisher. We were able to effectively sample side channels and shorelines with moderate water velocities, but we were ineffective at high water velocity sites and several chest-deep pools in these sections. Six backpack transects were established in these two sections (Table 1). Four transects (numbers 6,8,9, and 10) were routinely sampled while others were sampled as time permitted. All backpack electrofishing was conducted at night, utilizing large dive lights and a 12-V spotlight for illumination.

Habitat Characterization.-- A general shoreline habitat survey was conducted in June to describe and distinguish fish use in the three sections of the lower Cedar River. Habitat was described for each electrofishing transect. Lengths of transects were measured with a hip chain. Every 20 m the depth was measured to the nearest 0.05 m with a stadia rod. Depth measurements were taken 1-3 m from shore along the midline of each electrofishing transect. At the same locations, the percentages of different substrate types within a 2-m-diameter circle were visually estimated. Substrate was classified into five categories: silt (sediment size, < 0.1 mm), sand (0.1-2 mm), gravel (2-20 mm), cobble (20-200 mm), and boulders (> 200 mm). Percent of the shoreline length that had overhanging vegetation was visually estimated along each 20-m section. The presence/absence and type of instream structure were also noted.

Catch rates.-- To determine if numbers of predators increased at the mouth of the Cedar River during sockeye fry emigration, we calculated catch rates for beach seining and electrofishing. After capture, fish were anesthetized with MS-222 and identified to species. We separated *O. mykiss* into rainbow trout/steelhead and hatchery rainbow trout based on body coloration, body shape, and the presence of eroded fins. There was some degree of qualitative assessment in making these distinctions. Resident rainbow trout and steelhead were combined in the analysis, because of the difficulty in distinguishing the two unless the steelhead were smolted. During this study, 292,000 hatchery rainbow trout were planted in Lake Washington.

To compare locations within the study site, we grouped transects into three distinct areas (lower, middle and upper sections of the lower river). Total catch was calculated for each section to compare between dates. Total catch included three river electrofishing transects in the lower section and two in both the middle and upper sections. Catch per 100 m and catch per 10 minutes were also calculated to normalize the data. Catch rates were calculated for river beach seining, but changes in discharge and water level may have changed the catch efficiency between sample dates. Catch per set was used to normalize data.

Population size.-- Population sizes of cottids were estimated with mark-recapture methodologies (Ricker 1975). Because few other predatory fish were captured, we only estimated the population sizes of cottids. These fish were collected primarily with electrofishing equipment, although some cottids were collected by baited minnow traps (Rickard 1980) and by snorkelers with small aquarium dip nets (Hillman 1989). However, minnow traps and dip nets were generally inefficient in collecting cottids and were abandoned in favor of electrofishing. Both the initial collection and recapture were done with electrofishing equipment.

After capture, cottids were anesthetized with MS-222. Lengths were measured to the nearest mm and weights were measured to the nearest g. Stomach samples were also taken from a small subsample of cottids. Fish were marked with either a fin clip (Greenberg and Holtzman 1987; Morgan and Ringler 1992) or acrylic paint (Hill and Grossman 1987a). For fin clips, we clipped the lower section of the caudal fin. Non-toxic acrylic paint was injected with a 0.5 mm by 25 mm needle into the base of the anal fin (left or right side). We used seven different colors to distinguish between transects. A small number of prickly sculpin (N = 10) were injected with acrylic paint and held under laboratory conditions in a circular tank at 12°C. After 60 days, no loss of marks was seen. Hill and Grossman (1987a) reported retentions of 84% after 10 weeks and found that marks at the base of the pectoral, pelvic, or anal fins gave the best results. After marking the fish, we allowed them to recover and then released them along the same transect where they were caught.

To estimate the population sizes of different transects, we used a multiple censuses technique (modified Schnabel):

$$N = \frac{\Sigma(C_t M_t)}{R + 1}$$

where N = population size; C_t = total sample taken on day *t*; M_t = total marked fish at large at the start of the *t*th day (the number previously marked less any accidentally killed at previous recaptures); and R = total number of recaptures during the experiment. Approximate 95% confidence intervals were obtained from a Poisson distribution table (Ricker 1975). The time interval between the first marking and the last recapture date ranged from 8 to 33 days. Most population estimates were made for a single shoreline transect. In the lower section, three shoreline transects and a mid-channel transect were combined into one population estimate.

Due to the small sample sizes of some species of cottids, we combined all cottid species from each transect into a single population estimate. This assumes that all four species have similar catchabilities. In addition, we only marked cottids that were ≥ 60 mm TL. Thus, there was probably some recruitment of smaller cottids into this size class. We assume this was only a negligible amount of recruitment in relation to the population size. Growth of cottids in the Cedar River is unknown.

We assumed that electrofishing, marking, and handling had minimal effect on the survival of cottids. Barrett and Grossman (1988) found that electrofishing did not adversely affect the short-term (30 d) survival of mottled sculpin (*C. bairdi*). As part of another study, we kept 147 prickly sculpin that were collected during mark-recapture sampling and placed them in a small net-pen for one to four days. They were then transferred to circular tanks and held under laboratory conditions. After 30 days their survival rate was 97%. Thus, it appeared that our electrofishing and handling did not substantially affect the short-term survival rate of cottids.

During the one to five week interval between the first marking and last recapture, we assumed the movements of cottids were minimal. Studies of slimy sculpin (*C. cognatus*), mottled sculpin, and banded sculpin (*C. carolinae*) have indicated their movements are generally restricted to a small area (Bailey 1952; McCleave 1964; Brown and Downhower 1982; Greenberg and Holtzman 1987; Hill and Grossman 1987b; Morgan and Ringler 1992). Krejsa (1967) found that coastal populations of prickly sculpin undertake a downstream spring migration, whereas, inland populations only undertake local migratory movements. However, the extent of local migrations is not known. Little information is available concerning the movements of prickly sculpin in the Cedar River and Lake Washington. However, prickly sculpin in Lake Washington do appear to move offshore during the summer (Rickard 1980). In Sashin Creek, Alaska, coastrange sculpin (*C. aleuticus*) have been shown to move in response to the presence of salmon eggs (McLarney 1967). Little movement occurred prior to the arrival of adult pink salmon. In the Cedar River, local movements of cottids may also be related to prey availability, such as the abundance of sockeye salmon fry or longfin smelt (*Spirinchus thaleichthys*) eggs and adults. Of all the cottids we recaptured from March -June, 97% were found in the same transect where they were released. The others were found in adjacent or nearby transects. We sampled 52% of the shoreline of the study reach as well as most of the shoreline of southern Lake Washington as part of another study. Thus, we found no evidence for any extensive movements of cottids.

We calculated the density of cottids as the number per meter of shoreline. Snorkeling observations and electrofishing indicated the density of cottids was considerably higher within 2-7 m of shoreline than it was farther away. Areas away from the shoreline tended to have higher water velocities, and substantially less cover than along the shoreline. We assume that most cottids remained in the shoreline habitat and did not migrate to midchannel areas.

Stomach samples.-- After capture, stomach contents of most fish were removed using a gastric flushing apparatus modified from Foster (1977). Gastric lavage has been shown to be effective in removing stomach contents for many fish species. For example, Light et al. (1983) found the technique removed 100% of the stomach contents of slimy sculpin and 98% for brook trout (*Salvelinus fontinalis*). All stomach contents were put in plastic bags, placed on ice, and later froze. Samples remained frozen until laboratory analysis. On one date, several cottids were frozen whole due to time constraints, so shortly after capture, 95% ethyl alcohol was injected into their abdominal cavities to retard further digestion of the stomach contents.

In the laboratory, samples were thawed, examined with a dissecting scope, and divided into major prey taxa. We attempted to identify fish to species. Insects and crustaceans were identified to order, while other prey items were identified to major taxonomic groups. Sand and gravel found in the stomach samples were considered incidental and not used in any analysis. Each prey group was blotted by placing the sample on tissue paper for ≈ 10 s. Prey groups were weighed to the nearest 0.001 g. To reduce bias from different-sized fish, prey weights were converted to percent body weight (Hyslop 1980).

Prey fishes that were slightly digested were easily identified to species. Fishes in more advanced stages of digestion were identified to family, genus, or species from diagnostic bones (Hansel et al. 1988), gill raker counts, pyloric caeca counts, or vertebral columns. The fork length of prey fishes was measured to the nearest mm. If a fork length could not be taken, the original fork lengths of prey fishes were estimated from measurements of standard length, nape to tail length (Vigg et al. 1991), or diagnostic bones (Hansel et al. 1988).

RESULTS

Catch

In February and March, few predatory fish were collected in the lower Cedar River (Figures 5 and 6). Electrofishing catch throughout the sampling period was predominately composed of cottids. Cottids were also the primary fish species captured with beach seining equipment during the sample period. We were unable to sample with electrofishing or beach seining equipment in early February due to high flows and related turbidity. Electrofishing catch and beach seining catch rates were relatively low in March (Figures 5 and 7). Due to mechanical problems with the electrofishing boat and April/ May rain events we were unable to sample the lower section from approximately mid-April to mid-May.

Catch rates using distance shocked or time shocked were relatively similar in the lower river section (Figures 8 and 9). The lowest catch rates for cutthroat trout (*O. clarki*) and coho salmon (*O. kisutch*) were observed in the middle section, while the lowest catch rate for rainbow/steelhead was in the lower section. Catch rates of most salmonids were generally higher in the upper river section, while catch rates of cottid species were highest in the middle. Predatory fish other than salmonids and cottids (smallmouth bass and yellow perch), were found only in the lower and middle sections.

The only sample taken during May in the lower section followed a recent rain event. Turbidity for the sample date was unusually high compared to other sample dates in this section. The greatly reduced visibility, coupled with the depth of the lower section boat transects and cottid stun response to electrofishing, restricted our capture of cottids during this time. On this same sampling date, salmonid catches increased markedly.

Cottidae.-- There are four species of sculpin which inhabit the lower Cedar River. The dominant species was prickly sculpin followed by, in decreasing order of abundance, torrent sculpin (*C. rhotheus*), coastrange sculpin, and reticulate sculpin (*C. perplexus*). Catch of all species was low in late February and early March and then generally increased through the remainder of the sample period (Figure 5). Electrofishing catch of coastrange, reticulate and torrent sculpin in the lower section was extremely minor throughout the sample period. A marked reduction in electrofishing catch occurred in the lower section during the late May sample (Figure 5). This decrease can be attributed to the limited visibility caused by high turbidity at the time of sampling. A fairly large decrease in catch also occurred in the middle section in early May. This may be attributed to the effects of a late April flood event which occurred between the sampling dates. Much of the complex cobble/boulder habitat in transect 6, which had previously yielded many sculpin, had been filled in by flood sedimentation. From March to June, beach seine catch rate for all cottids, except coastrange sculpin, had at least doubled (Figure 7).

Catch of prickly sculpin was greatest in the lower section followed by the middle and upper sections. Prickly sculpin collected in the lower section were also generally larger-sized, ranging up to 221 mm TL versus only 148 mm TL in the middle and upper sections (Figure 10). Over half the prickly sculpin (52%) collected by electrofishing in the lower section were between 100-140 mm TL. The majority of prickly sculpin collected in the middle (88%) and upper (86%) sections were between 60-100 mm TL. Beach seine catches of prickly sculpin were also much higher in the lower section than the middle section (Figure 7). Prickly sculpin captured by beach seining ranged up to 140 mm TL. However, most prickly sculpin (80%) collected in the lower section with the beach seine were between 60-100 mm TL (Figure 11).

Torrent sculpin were present in all sections of the lower river, but appear to be most abundant in the middle and upper sections (Figures 8 and 10). Length frequency data indicate that larger torrent sculpins tended to be in the lower and upper sections. The largest torrent collected was 131 mm TL, and was caught in the upper section. Most torrent sculpin (86%) collected by electrofishing were between 60-80 mm TL. The few torrents captured by beach seining (N=24) were all < 90 mm TL (Figure 11).

Catch of coastrange sculpin was highest in the middle section (Figures 10 and 11). This species ranged up to 110 mm TL. Sixty-five percent of the coastrange sculpin collected by electrofishing in the lower Cedar River were 60-80 mm TL. The majority of coastrange sculpin (95%) captured with the beach seine were 50-80 mm TL.

All but one of the reticulate sculpin were captured in the middle and upper sections of the study area. Most reticulate sculpin collected in the middle (72%) and upper (93%) sections were 60-80 mm TL (Figure 10). No reticulate sculpin were captured by beach seining in midchannel areas.

Salmonidae.-- Cutthroat trout catches in all sections generally increased slightly through March and April and then decreased in May and June. A large peak in catch occurred in the lower section, coinciding with the post rain event in late May (Figure 6). Most cutthroat trout (67%) were 120-200 mm FL (Figure 12). Three fish (7%) were > 280 mm FL and were all captured in the lower section. Six fish (14%) were < 120 mm FL, the smallest of which was a 70 mm FL individual caught in the upper section. None of the cutthroat trout in the < 120 mm FL size range were captured in the middle section.

Rainbow trout/steelhead were captured in all sections of the lower Cedar River. Overall catch was low, with most fish captured in the lower and upper sections. Approximately a quarter of the combined catch was comprised of steelhead smolts. Two steelhead smolts were captured in March in the upper section and three in May in the lower section. Most rainbow trout/steelhead (47%) were 160-200 mm FL (Figure 12). Four rainbow trout (21%) were > 300 mm FL, and were most likely a resident form based on body shape.

Only four hatchery rainbow trout were captured during the sample period and all were caught in the lower section in late May and early June.

Coho salmon smolts were captured from mid-March to late May. Seventy-five percent of the coho smolts identified in March and April were caught in the upper section. Captures in late May all occurred in the lower section (Figure 6). Coho smolts ranged between 94-141 mm FL. Most coho smolts (67%) were 100-120 mm FL (Figure 12).

Four mountain whitefish (*Prosopium williamsoni*) were collected in the lower section during the sample period. Fish ranged between 245-405 mm FL. One whitefish was captured in late February and three in late May. No whitefish were captured with the beach seine.

Ictaluridae.-- One brown bullhead (*Ictalurus nebulosus*) (164 mm FL) was collected in the upper section of the lower Cedar River. It was caught in the backwater pool under the upper Boeing Bridge in early June.

Centrarchidae.-- Three smallmouth bass (*Micropterus dolomieui*) were collected in the lower Cedar River. Two (290 mm and 308 mm FL) were captured in the lower section during the post rain event sample in late May, and one (277 mm FL) was collected in the middle section (transect 6) in early June. In addition, two juvenile pumpkinseed (*Lepomis gibbosus*) were collected.

Percidae.-- Only two yellow perch (*Perca flavescens*) (136 mm and 159 mm FL) were collected in the lower Cedar River. Both were caught in early June, one in the lower and one in the middle sections.

Habitat Characterization

Habitat of shoreline transects was surveyed on June 19, 1996. The mean discharge for that date was 10.6 m^3/s (USGS, unpublished data). Because the lake level was at the maximum elevation of 6.7 m, the amount of backed up water from Lake Washington was at its greatest. During the sampling period (February-June), habitat conditions (i.e., depth) would have been variable depending on discharge and lake levels. However, the June 19 survey provided a rough approximation of the differences in habitat between transects. Further sampling is needed to more accurately describe the habitat during different discharge and lake levels.

Lower section.--This section contained the area around the lower Boeing Bridge in addition to the first 400 m of the right and left bank shoreline upstream from the Cedar River mouth. Transects 1 and 2, which were the downstream and upstream sides of the bridge, were the deepest areas sampled (Table 2). Substrate consisted of primarily sand and gravel with minor amounts of boulder riprap at the bridge margins. Instream structure/cover in these two transects consisted of partially submerged steel bridge supports and concrete bridge abutments. A number of small to medium-sized woody debris pieces had deposited in the area around the bridge. Transects 3-5 had large sections of bulkhead or gabion along the bank (Table 2). Cobble and boulder riprap, incorporated into these bank stabilizing structures, dominated these transects. This shore area was ideal habitat for large cottids. Overhanging vegetation in the lower section consisted of primarily scotch broom, berry vines, and willow. Beach seining site 1 ranged from 0.4-1.5 m in depth. Substrate composition of the site was primarily sand and silt, with small amounts of gravel. Small pieces of submerged woody debris were also present.

Middle section.--Shoreline transects 6-8 were dominated by gravel and sand substrate. Transects 6 and 7 had remnants of old bulkhead structures which would trap pieces of small woody debris. High percentages of overhanging vegetation were recorded in both these transects (Table 2), consisting primarily of alder trees, scotch broom, berry vines, and willow. Transect 8 had little overhanging vegetation, but had several areas of submerged grasses which attracted numerous cottids. The upstream end of transect 8 included a large log with associated small woody debris. The average depths sampled in this section were less than half of the shallowest depth sampled in the lower section. The beach seine sites 2 and 3 were generally < 0.5 m in depth. Substrate was dominated by gravel (> 80%) with minor percentages of sand.

Upper section.--Transect 9 contained the left bank area around the upper Boeing Bridge. The transect was dominated by a gravel and cobble substrate, with small amounts of silt associated with the backwater pool under the bridge (Table 2). Most overhanging vegetation was upstream and downstream of the bridge, and consisted primarily of alder and willow. Instream cover included the bridge and a woody debris jam associated with the structure. Transect 10 shoreline had numerous small backwaters dominated by gravel and sand substrate. Percentage of overhanging vegetation (70.6%) in transect 10 was the highest for all sections. Throughout the transect, the vegetation was primarily willow and alder trees. In many areas, branches were near or below the water line which could trap small woody debris. The average sampling depth in the upper section was < 0.25 m.

Population size

The results of our mark-recapture population estimates are presented in Table 3. Although we marked large numbers of cottids, our recapture rates were generally low. Thus, an individual recaptured fish can have a large impact on the population estimate. Low numbers of recaptures resulted in relatively large confidence intervals. Although our estimates are probably biased somewhat due to the low recapture rates, the results suggest that cottids in the lower Cedar River are generally abundant. Based on 1995 population estimates of salmonids (Tabor and Chan 1996) and 1996 catch rates, cottids appear to be substantially more abundant than predatory salmonids in the lower Cedar River.

The highest shoreline densities of cottids were observed in the middle section (Table 4). The lower and upper sections had similar shoreline densities. Calculations of catch rates (number/100 m) showed a similar pattern.

Stomach analysis

Stomach analysis and catch data from electrofishing and beach seining indicated that, within the Cedar River study area, the majority of predation on sockeye salmon fry occurred in the lower 440-m reach (Tables 5 and 6). However, predation rates on salmonid fry were also relatively high at transect 9, which is a backwater area in the upper section. Little predation of sockeye salmon fry was detected in the middle section or at the other transect (number 10) in the upper reach.

During hatchery fry releases on February 26, February 28, and March 6, discharge ranged from 17.5 to 34.2 m^3/s and little predation was observed. Turbidities were also higher during those dates than during later fry releases. During hatchery fry releases on March 18, March 20, and March 26, however, discharges (11.2-12.4 m^3/s) and turbidities were lower. Predation rates were substantially higher during these later hatchery fry releases. For example, in prickly sculpin stomachs there was only 0.08 fry/stomach (1/14) during the earlier releases, whereas during the later hatchery fry releases there was an average of 1.12 salmonid fry/stomach (156/139).

<u>Cottidae</u>.-- On nights when hatchery fry were released (March), sockeye salmon fry were the dominant prey item of prickly sculpin between 50 and 99 mm TL (Figure 13). The remainder of the stomach contents included oligochates, fish eggs (primarily longfin smelt eggs) and aquatic insects (primarily mayflies). Prickly sculpin between 100 and 149 mm TL also appeared to consume large numbers of sockeye salmon fry (Table 7). However, for prickly sculpin ≥ 150 mm TL, few sockeye salmon were consumed. The main diet item for prickly sculpin ≥ 150 mm TL was adult longfin smelt (Figure 13). Adult longfin smelt were also the most important diet item for prickly sculpin between 100 and 149 mm TL. The smallest prickly sculpin to ingest an adult longfin smelt was a 102 mm TL individual which consumed a 85 mm FL smelt. Stomach samples of prickly sculpin ≥ 100 mm TL also contained some cottids (Table 7). Overall, more than 90% of prickly sculpin (≥ 100 mm TL) diet consisted of prey fish. Most longfin smelt die shortly after spawning, thus prickly sculpins may have consumed longfin smelt that were already dead. However, many of the longfin smelt found in the stomachs of prickly sculpin contained large numbers of eggs, thus indicating they had not spawned yet and probably were consumed alive.

A few sockeye salmon fry were present in prickly sculpin stomach samples in April (Table 7). The prickly sculpin that did consume sockeye salmon fry were all < 125 mm TL and were collected in backwater areas. The main diet items of prickly sculpin < 100 mm TL were aquatic insects (mostly larval dipterans), oligochaetes, and fish eggs (mostly longfin smelt eggs). In April, adult longfin smelt continued to be the most important prey item for prickly sculpin ≥ 100 mm TL (Figure 13). Other prey fish were either cottids or unidentified fish. Little else was present in the stomachs except some fish eggs and a few aquatic insects.

In May and June, no sockeye salmon fry or longfin smelt were present in the 112 prickly sculpin stomachs examined. The main prey items of prickly sculpin < 125 mm TL were aquatic insects (primarily larval chironomids and mayfly nymphs), oligochaetes, leeches, and fish eggs (Figure 13). Prickly sculpin ≥ 125 mm TL continued to consume relatively large prey which included crayfish, cottids, lamprey ammocoetes, and adult brook lamprey (*Lampetra richardsoni*). Unlike salmonids, few larval fish were consumed by any size class of prickly sculpin.

Among torrent sculpin, sockeye salmon fry made up 65% of their stomach contents during the March hatchery releases (N=9, Figure 14). Torrent sculpin that had consumed sockeye salmon fry were all collected by beach seining at the lowest site. The smallest cottid we recorded to have consumed salmonid fry was a 50 mm TL torrent sculpin which had two sockeye salmon fry present in its stomach. Other prey items found in the stomachs of torrent sculpin included aquatic insects, longfin smelt eggs, leeches, and cottids. The diet of torrent sculpin from April to June consisted primarily of aquatic insects, cottids, lamprey, oligochaetes, and salmonid fry (Figure 14). Torrent sculpin that had preyed on salmonid fry were collected in backwater areas.

During March, we sampled 56 coastrange sculpin for stomach contents. Most of this species were collected with beach seines. The diet of both size classes examined (50-74 and 75-105 mm TL) was dominated by longfin smelt eggs (Figure 15). A total of six salmonid fry were found in the 45 stomachs of the 50-74 mm TL size class. Besides longfin smelt eggs (93%) and salmonid fry (6%), little else was present in their stomachs. No fry were found in the stomachs of the 75-105 mm TL size class. However, one 46 mm TL cottid was consumed by a 101 mm TL coastrange sculpin. The diet consisted mostly of longfin smelt eggs (77%), stonefly nymphs (10%), and cottids (6%).

Of the 38 coastrange sculpin stomachs examined from April to June, the only fish remains seen were two unidentified larval fish (10-11 mm TL). The diet was composed primarily of aquatic insects (Figure 15). Larval chironomids were the most important prey items, occurring in 68% of the stomachs examined and representing 27% of the diet by weight. Other aquatic insects included mainly mayfly nymphs, larval caddisflies, and stonefly nymphs. Fish eggs (which appeared to be catostomid and cottid eggs) made up 34% of the diet of coastrange sculpin ≥ 75 mm.

Only one stomach sample of a reticulate sculpin was taken during February - March. One well digested salmonid fry (0.002 g) was present. The fry was apparently ingested prior to the hatchery release of sockeye fry. The stomach sample also contained leeches (80%), amphipods (4%), and chironomid larvae (4%). Eleven reticulate sculpin stomachs were examined from April-June. Fifty seven percent of the stomach contents of small reticulate sculpin (50-74 mm TL) was detritus, which was present in two of the three stomachs examined. The detritus may have been ingested during the capture of prey. Mayfly nymphs (36%), larval chironomids, juvenile crayfish (2.3%), and amphipods (2.3%) accounted from the rest of the stomach contents. The diet of large reticulate sculpins (75-105 mm TL) included oligochates (53%), crayfish (26.9), mayfly nymphs (9%), and larval caddisflies (5%).

Salmonidae.-- During the February and March hatchery fry releases, 14 cutthroat trout were collected for stomach analysis. Most of the predation of sockeye salmon fry was observed in cutthroat trout < 150 mm FL (Figure 16). The stomach of the smallest cutthroat trout (70 mm FL) collected contained three sockeye salmon fry. During the entire sampling period, adult longfin smelt were the dominant prey of cutthroat trout > 150 mm FL. Even in May and June, when few adult longfin smelt were apparently present in the Cedar River, smelt were still an important prey item of cutthroat trout > 150 mm FL. Other important diet items of cutthroat trout included aquatic and terrestrial insects and catostomid eggs and larval.

Of the eleven rainbow trout collected shortly after the hatchery releases, only one contained any sockeye salmon fry. Most rainbow trout stomachs contained several aquatic insects, primarily larval caddisflies. Most of the stomach contents by weight of rainbow trout > 200 mm FL consisted of adult longfin smelt. One 480 mm FL rainbow trout collected in February at the mouth of the Cedar River had consumed eight adult longfin smelt. During April-June the main prey items of rainbow trout were aquatic and terrestrial insects, zooplankton, and fish eggs. Zooplankton (primarily cladocerans) were only present in the stomachs of recently stocked rainbow trout. These fish had apparently foraged in the lake, and soon after had moved into the river.

During the hatchery releases in February and March, 81.5% of the stomach contents of juvenile coho salmon was composed of sockeye salmon fry (Figure 17). Aquatic and terrestrial insects (15.9%) made up most of the remainder. In April-May, the diet was composed mostly of aquatic and terrestrial insects (48%) and fish eggs (26.1%). Sockeye salmon fry made up 7.8% of the diet during this period.

We also examined the stomachs of three juvenile chinook salmon in May. The diet was composed mostly of aquatic and terrestrial insects (65%) and fish eggs (34%). In February and March, the juvenile chinook salmon were relatively small and were not considered a major predator of sockeye fry.

Fish eggs (62%) and aquatic insects (18%) were the dominant prey items of the two mountain whitefish sampled in February (Figure 17). Aquatic insects (66%) and plant material (34%) were the only prey items present in the two mountain whitefish examined in May. No evidence of piscivory was observed.

Ictaluridae.-- The stomach of the single brown bullhead collected in the Cedar River contained plant material (33%), aquatic insects (26%), clams (8%), and unidentified material (33%). No fish remains were present.

Centrarchidae.-- Besides cottids (99.5%), little else was present in the stomachs of the two smallmouth bass collected in the lower section. A total of four cottids were observed in the stomachs. A third smallmouth bass, collected in the middle section, had an empty stomach.

Percidae.-- Both yellow perch that were caught had empty stomachs.

DISCUSSION

Abundance of predators.--Comparison of catch rates between study years indicate a substantial decrease in predatory salmonids collected in 1996. Catch of all salmonid species including mountain whitefish was very low. Catch rate of salmonids was three to ten times higher in 1995 depending on species. For example, no adult mountain whitefish were captured by beach seining efforts on March 20 and June 6, 1996. However, on March 30 and June 1, 1995, catch rates were 1.3 and 2.8 per set respectively. Catch rates for cottids were not calculated in 1995. However, a qualitative assessment of catch based on observations during shocking would indicate that cottid numbers in general were similar if not greater in 1996. Cottid abundance by species is probably regulated by several factors such as competition, predation, and habitat availability during most years. However, additional factors such as habitat selection in terms of potential refugia may be important during flood event years.

Based on catch rates, the abundance of cottids appeared to increase during the sampling period. The increase in cottid abundance may reflect recolonization after the winter floods. Fausch and Young (1995) provide examples of rapid recolonization by fish species (including cottids) in experimentally and naturally depleted stream reaches. Recruits may have come from locations upstream of the sample area, but mark recapture efforts indicate little movement between sites. In addition, low temperatures during the early part of the study may have depressed sculpin activity. Sculpin would have become more active with increasing temperatures and perhaps more vulnerable to capture. In Lake Washington, minnow trap catch rates of prickly sculpin were at their lowest in February and March when the water temperatures were at their lowest (Rickard 1980). Other species of cottids have been shown to actively feed during the winter (Bailey 1952; Daiber 1956). However, the seasonal activity patterns of cottids are not well known.

The low number of salmonids may be the result of displacement from the large flood events which occurred in November 1995 and February 1996. The lower 1,700 m of the Cedar River lacks large pools, stable substrate, and permanent instream structure, and is heavily armored along most of its shoreline. Pearsons et al. (1992), found that fish assemblages in less complex habitats were more susceptible to flood disturbance effects. Fish may move or be displaced to areas with deep pools and stable structure, which act as refugia during floods (Sedell et al. 1990; Pearsons et al. 1992). Fish such as juvenile and adult salmonids, which may not have been able to utilize the limited shoreline refugia (i.e. mainly cobble and riprap), may have been displaced into the lake environment. Species such as cottids, which could more effectively use the armored shoreline as refugia, would have been less affected by the large scale flooding.

The sharp increase in salmonid catch in the lower section in late May may be the result of several factors. Reactive distance of predators to the electrofishing boat may have been greatly reduced due to the increase in turbidity. Increases in electrofishing catch related to elevated turbidity have been noted in other studies (Kirkland 1962; Shively et al. 1991). However, most catches in 1995 were at least equal to or higher than the late May 1996 sample and, during 1995, the level of turbidity was always low when predators were collected. An increase in forage may have influenced the influx of salmonids into the lower Cedar River. Sharp increases in discharge can raise the amount of drift fauna and cause benthic invertebrates to be displaced downstream creating additional forage for fish (Hynes 1970). However, studies have shown reactive distance of visual predators decreases with increasing turbidity (Vinyard and O'Brien 1976; Crowl 1989).

Low numbers of coho salmon were captured in the lower Cedar River throughout the 1996 sampling period. We were unable to sample in the lower river during the peak emigration period in late April, but catches of coho salmon smolts in southern Lake Washington also indicated a lower abundance in 1996. The smolts that emigrated during the sampling period in 1996 were from a very low escapement year, brood year 1994. The wild coho escapement for the Lake Washington Basin in 1994 was estimated at 200 adults compared to 1,600 in 1993 (C. Baranski, WDFW, personal communication).

Habitat utilization.--Cottids appeared to be segregated not only by species but also by their size in the lower Cedar River. Water velocity and depth seemed to be the obvious factors influencing habitat use among species, but substrate, cover, predation and competition may also be important.

Primary use of the lower and middle sections by prickly sculpin would indicate a strong habitat preference for the areas of least velocity and greatest average depth. McPhail and Lindsey (1970) and Scott and Crossman (1973) note that prickly sculpin usually inhabit areas of quiet water and avoid strong currents, and may also occur along lake shores. Brown et al. (1995) showed prickly sculpins were negatively correlated with gradient and positively correlated with percentage of sand substrate in tributaries to a coastal river in California. Prickly sculpin ≥ 150 mm TL appear to prefer the lower section, the deepest habitat in the study site. Large prickly sculpin were observed at all depths perched within the numerous interstitial spaces along the bulkhead head walls and support pilings. Smaller sculpin (< 90 mm TL) were observed primarily on top of the shelf areas of the bulkheads. The low numbers of small prickly sculpin captured in the lower section may be a result of limitations of the boat electrofishing gear in these areas. The large dip nets utilized for boat electrofishing were less effective in capturing small sculpin on uneven cobble and boulder substrates. However, large prickly sculpin may exclude smaller sculpin from deeper habitats through competition or predation. Mason and Machidori (1975) observed that large prickly sculpin occupied the deepest locations in pools and intermediate-sized prickly sculpin were found at shallower depths. Field tests with mottled sculpin have demonstrated this differential depth selection when different size classes occupy the same area (Freeman and Stouder 1989).

In contrast, coastrange sculpin typically occur in the fast water of streams and rivers and usually on gravel substrate (McPhail and Lindsey 1970; Scott and Crossman 1973). Ringstad and Narver (1973) found that in late summer, coastrange sculpin occur under rocks in moving water while prickly sculpin occur in quiet water under cover such as roots and cutbanks. Coastrange sculpin captures would suggest that they can live in a wide variety of habitats in the lower Cedar River, but prefer to inhabit higher current areas (middle and upper sections). Beach seine catches indicate coastrange sculpin is the dominate cottid in the mid-channel gravel areas. The low abundance of coastrange sculpin along the shoreline, relative to prickly and torrent sculpin, may be the result of the coastrange sculpin's strong association with this mid-channel environment which tends to be highly unstable in the lower Cedar River. Large shifts in bedload have been observed in the Cedar River following high-water or flood events, which could directly affect benthic species such as sculpin. Erman et al.(1988) found dead Paiute sculpin (*C. beldingi*) in bedload samples after flood events caused increases in bed material transport. Competition with prickly sculpin and torrent sculpin may also be excluding coastrange sculpin from other areas. In upstream areas where prickly sculpin are absent, coastrange sculpin have been observed to inhabit both pools and riffles (Ringstad and Narver 1973; Mason and Machidori 1975). Coastrange sculpin lead a pelagic existence in Lake Washington, but how it relates to the stream-dwelling form in the Cedar River is unknown (Ikusemiju 1974).

Torrent sculpin which utilize stream environments generally live in areas of swift current (e.g., riffles) with stable rubble, cobble, and gravel substrate (Wydoski and Whitney 1979; Finger 1982). This would be consistent with the higher electrofishing catch rates of torrent sculpin in the middle and upper sections, which were dominated by riffle habitat. Torrent sculpin preference for stable substrates may explain their low abundance in the mid-channel areas sampled by beach seine. Torrent sculpin are known to also inhabit lake shorelines (Scott and Crossman 1973). Northcote (1954) found torrent and prickly sculpin together during beach seine hauls at the Arrow Lakes in British Columbia, suggesting a close association between the two species. Although we always found prickly and torrent sculpin together during sampling, the catch of prickly sculpin compared to the catch of torrent sculpin was always much higher in the lower and middle sections and approximately equal in the upper section.

Although reticulate sculpin are known to inhabit a wide range of substrate types and current velocities (Wydoski and Whitney 1979, Finger 1982), we captured reticulate sculpin only in our middle and upper shoreline transects. This observation, combined with the fact that reticulate sculpin were never captured in the mid-channel areas, would indicate that distribution may be influenced more by species interactions than by physical factors such as current velocity and substrate type. Bond (1963) notes that when torrent and coastrange sculpin are found in riffles of a particular stream, the reticulate sculpin is usually confined to the pools or along the shore.

Salmonids were generally associated with areas that had relatively deep water and instream structure. Small pockets of this type of habitat occurred in the middle and upper sections, such as under the upper Boeing Bridge, but most were located in the lower section. Depth appeared to be increasingly important in determining habitat use as cutthroat and rainbow trout increased in size. Fish > 280 mm FL were captured only in the lower section. However, this may be a reflection of the different capture techniques utilized in this study for the various sections.

Predation.-- The vast majority of predation we observed occurred in the lower 440 m of the river. This section is generally backed up water from Lake Washington and is deeper and has lower water velocities than other study areas (Figure 3). Outside of the lower section, the only other location where predation of fry was detected was transect 9, which is mostly a backwater eddy near the upper Boeing Bridge. On several occasions, we observed large numbers of sockeye salmon fry in this site. Overall, it appeared that areas of reduced water velocities such as pools or backwaters were the major locations of sockeye fry predation.

Predation rates also appeared to be related to discharge levels. We observed low predation rates at discharge levels > 17 m^3/s. Seiler and Kishimoto (1996) found that survival rates of hatchery sockeye salmon fry in the Cedar River (from Landsburg Dam at rkm 35.1 to a fry trap at rkm 0.7) were correlated significantly with discharge. At 10 m^3/s, hatchery sockeye salmon fry would be predicted to have a survival rate of ≈23%, whereas at 17 m^3/s the survival rate would be ≈44%. During fry emigration, most mortality is from predation (Foerster 1968). At low discharge levels, the mean velocity is reduced and the duration of fry emigration is increased. Consequently, fry are exposed to predators for a longer period of time. As discharge is reduced the stream channel roughness is increased. Therefore, fry may be more likely to become trapped in eddies, such as site 9. Additionally, the water depth is decreased and fry will be closer to cottids and other predators.

Turbidity is often increased during periods of high discharge levels. Increased turbidity greatly reduces the reactive distance of visual predators (Vinyard and O'Brien 1976; Crowl 1989). Consequently, the foraging ability of many piscivorous fishes is greatly reduced. Rainbow trout have been demonstrated to predate less effectively on sockeye salmon fry during periods of increased turbidity (Ginetz and Larkin 1976). Salmonids that inhabit the lower Cedar River would generally be considered visual predators. However, the importance of vision in locating prey for cottids is not well known. Hoekstra and Janseen (1985) found that blinded mottled sculpin could feed on a variety of motile prey in the laboratory.

The size of prey consumed by prickly sculpin suggests that they are size-selective predators. For example, larger sculpin (i.e., ≥ 150 mm TL) tend to prey on larger prey such as adult longfin smelt and ignore smaller prey such as sockeye salmon fry or aquatic insects. Rickard (1980) found that the maximum length of prickly sculpin that had consumed chironomids or trichopterans was 154 mm TL, while the maximum length to consume fish or crayfish was 177 mm TL. Size-selective predation has been documented in slimy sculpin (Newman and Waters 1984) and fourhorn sculpin (*Myoxocephalus quadricornis*, Leonardsson et al. 1988). Both studies indicate that sculpin tend to select the largest individuals of a particular prey type. In both studies the prey was considerably smaller than the predator. In the Cedar River, some portion of the population of longfin smelt, cottids, and crayfish may be too large for prickly sculpin to handle. For these species, prickly sculpin may only be able to prey on the smaller individuals. In Elokomin River, Washington, the mean length of juvenile chinook salmon released was 59 mm FL but the mean length of those in cottid stomachs was 43 mm FL (Patten 1971b). Thus, prickly sculpin probably select the largest prey available up to a certain threshold size.

Our data suggest cottids, that are at least 50 mm TL, are capable of consuming sockeye salmon fry. The smallest cottid we recorded to have consumed salmonid fry was a 50 mm TL torrent sculpin which consumed a 29.5 mm FL sockeye salmon fry. For prickly, coastrange, and reticulate sculpins, the smallest fish to consume salmonid fry was 53, 60, and 58 mm TL, respectively. Gaudin (1985) found similar results for *C. gobio* feeding on trout fry under laboratory conditions. The limit of predation was described by the equation $Y = 0.484X + 5.8$ (Y = trout fry TL in mm and X = sculpin TL mm). For example, the limit for a 50 mm TL sculpin would be a 30 mm TL trout fry. Because sockeye salmon fry typically range from 25-30 mm FL, cottids ≤ 49 mm TL may also be capable of preying on fry. However, because we did not examine the stomach contents of cottids ≤ 49 TL mm, further work is needed to determine their consumption rates of salmonid fry. We would expect that cottids ≤ 49 mm TL will have low consumption rates of salmonid fry but they may be important predators if they are abundant.

How cottids are able to effectively capture sockeye salmon fry is unknown. Because sockeye salmon fry typically swim downstream near the surface (Hartman et al. 1962), it is somewhat surprising that benthic predators such as cottids can capture large numbers of fry, especially since much of the observed predation presumably occurred in relatively deep water. Visual observations of prickly sculpin in circular tanks (≈ 0.5 m deep) indicated they could easily capture trout fry at the surface (G. Brown, National Biological Service, personal communication). Prickly sculpin would appear motionless on the bottom and then make quick, darting movements to the surface to capture fry. Patten (1971a) suggested torrent sculpin were able to effectively capture coho salmon fry at the surface of 0.6 m-deep stream aquaria during moonlight nights. In the lower Cedar River, sockeye salmon fry could be closer to the bottom than in other streams due to the large amount of artificial lighting along the shoreline. Newly emerged sockeye salmon fry are negatively phototactic (Hartman et al. 1962) and seek holding areas along the stream banks during daylight hours. Therefore, sockeye salmon fry in the lower Cedar River could possibly be closer to the bottom and less active and more vulnerable to predation by cottids.

Prickly sculpin appeared to be the most important cottid predator of sockeye salmon fry because of their abundance, high consumption rates of fry, and their large size. Torrent sculpin also had relatively high consumption rates of fry but were substantially less abundant than prickly sculpin.

Northcote (1954) showed that torrent sculpin were more piscivorous and fed on larger prey items than prickly sculpin of equal size. The author felt this was because torrent sculpin have a wider mouth than prickly sculpin (Northcote 1954). In Elokomin River, Washington, torrent sculpin preyed on hatchery released chinook salmon (mean, 59 mm FL) at a smaller size than did prickly sculpin (Patten 1971b). Although torrent sculpin are highly piscivorous, their overall consumption of sockeye salmon fry in the lower Cedar River is considerably less than prickly sculpin because they are less abundant and few are more than 100 mm TL.

Coastrange sculpin did not appear to be important predators of sockeye salmon fry. Their diet consisted of smaller prey items (longfin smelt eggs and larval chironomids) than that of other cottid species. Coastrange sculpin have smaller mouths than the other cottid species (Patten 1971b). In the Elokomin River, Washington, coastrange sculpin were an insignificant predator of hatchery released chinook salmon (mean, 59 mm FL)(Patten 1971b). In the Cedar River, they may be an important predator of sockeye salmon eggs. In other systems, they have been documented to consume large numbers of salmonid eggs (McLarney 1967; Roger 1971). Of the fish species we examined, coastrange sculpin were the major predator of longfin smelt eggs.

Because we collected few reticulate sculpin following the hatchery fry releases, we were not able to accurately determine their consumption rate of sockeye salmon fry. However, because they only inhabited the shoreline areas and few were present in the lower section, they did not appear to be an important predator of sockeye salmon fry. In contrast, Patten (1971b) found that reticulate sculpin consumed large numbers of hatchery released chinook salmon (mean, 59 mm FL) in the Elokomin River, Washington. In an aquarium, reticulate sculpin were shown to move into the substrate to consume recently-hatched salmonid fry (Phillips and Claire 1966). In Rock Creek, Oregon, the diet of reticulate sculpin consisted primarily of aquatic insects, however some prey fish were also consumed (Pasch and Lyford 1972). Little other work has been done on the diet of reticulate sculpin. Further sampling is needed to determine their overall diet and consumption of sockeye salmon fry.

A dredging project to deepen the channel of the Cedar River would increase the length of the lake backwater and would probably increase the number of sockeye salmon fry consumed by cottids. Estimates of fry consumption and cottid abundance in the lower section would probably be the best predictors of the increase in predation. To calculate consumption by cottids, information is needed on their digestion rates. However, no data are currently available on digestion rates of the four cottid species observed in the Cedar River. Crude consumption estimates can be calculated if we assume that minimally digested fry were freshly ingested and were the only fry consumed from the hatchery fry emigration. A total of 115 minimally digested sockeye salmon fry were observed in the 130 prickly sculpin stomach samples collected during low flow conditions (< 13 m^3/s). If we use the observed shoreline abundance estimate of 3.6 prickly sculpin per meter, then the total shoreline predation in the lower section would be 2,457 fry per hatchery release (3.2 fry/m of shoreline). Our crude predation estimate of 3.2 fry/m of shoreline is only for hatchery releases during low discharge conditions. The predation rate would be expected to be lower as discharge and turbidity are increased, or density of sockeye salmon fry is decreased. For torrent and coastrange sculpin, the estimate for each hatchery release would be 62 and 10 fry, respectively (0.08 and 0.01 fry/m of shoreline).

Predation rates can also be calculated by area; however we have little information on the abundance of cottids in the mid-channel of the lower section. Preliminary electrofishing observations in the mid-channel indicated some cottids were present, but their density was substantially less than along the shoreline. Therefore, shoreline estimates could not be used to calculate their abundance in the entire lower section. Alternatively, a conservative estimate could be made by assuming that the total predation of fry in the mid-channel area is minimal compared to the shoreline areas. Thus, we would simply use the shoreline estimate as the total predation estimate.

CONCLUSIONS

1) The 1996 catch rates indicated a substantial decrease in the abundance of predatory salmonids in the lower Cedar River from 1995 levels. Catch of all salmonid species including mountain whitefish was very low. Catch rate of salmonids was three to ten times higher in 1995 depending on species. Recent floods may have displaced salmonids and other fish downstream.

2) Prickly sculpin inhabited slow-velocity waters, either in deep pool habitat or along the shoreline. Coastrange sculpin were found mostly in the midchannel area where higher water velocities were present. Reticulate sculpin were found along the shoreline. Torrent sculpin were scattered among all habitats but the highest abundance was in the middle and upper sections of the study site.

3) The vast majority of predation on sockeye salmon fry occurred in the lower 440-m reach. The only other area where predation was observed to any extent was at transect 9, a backwater area near the upper Boeing Bridge. It appears that such pools or backwaters with reduced water velocities are the major locations of sockeye fry predation.

4) Little predation was detected during the first three hatchery fry releases we sampled. Discharge and turbidities levels were relatively high during these releases. Predation rates were substantially higher during the later hatchery fry releases. For example, in prickly sculpin stomachs there was only 0.08 fry/stomach (1/14) during the earlier releases, whereas during the later hatchery fry releases there was an average of 1.12 salmonid fry/stomach (156/139).

5) Prickly sculpin appeared to be the most important predator of sockeye salmon fry because of their abundance and high consumption rates of fry.

6) Consumption of sockeye salmon fry was observed primarily in prickly sculpin $<$ 150 mm TL. The most important prey item of prickly sculpin $\geq$ 100 mm TL was adult longfin smelt

7) Torrent sculpin also had relatively high consumption rates of sockeye salmon fry; however, few were present in the lower section. Coastrange sculpin and reticulate sculpin did not appear to be important predators of sockeye salmon fry.

8) A dredging project to deepen the channel of the Cedar River would reduce water velocities in some areas and would probably create additional foraging sites for prickly sculpin and other piscivorous fishes. An increase in predator abundance may increase the overall predation level and have a negative impact on the emigrating sockeye salmon fry population. The extent of this impact would probably depend on discharge, turbidity, density of sockeye salmon fry, and abundance of alternative prey such as longfin smelt.

ACKNOWLEDGEMENTS

We wish to especially thank D. Rondorf and T.P. Poe of NBS for use of their electrofishing boat. We thank M. Carr and K. Fresh, WDFW; E. Warner, Muckleshoot Tribe; and M. Martz and F. Goetz, USACE for their assistance in designing this study. M. Carr, WDFW; E. Warner, Muckleshoot Tribe; S. Hager, M. Kelly, R. Peters, USFWS; J. Dillon, and M. Martz, USACE; and A. Fayram, University of Washington assisted with the field work. We gratefully acknowledge C. Cook-Tabor, USFWS, for the diet analysis. B. Wunderlich, USFWS reviewed an earlier draft of this report. The study was funded in part by the USACE (Military Interdepartmental Purchase Request Number E86-96-3062).

REFERENCES

Anderson. 1985. The structure of sculpin populations along a stream size gradient. Environmental Biology of Fishes 13:93-102.

Bailey, J.E. 1952. Life history and ecology of the sculpin *Cottus bairdi punctulatus* on southwestern Montana. Copeia 1952:243-255.

Barrett, J.C. and G.D. Grossman. 1988. Effects of direct current electrofishing on the mottled scuplin. North American Journal of Fisheries Management 8:112-116.

Bond, C.E. 1963. Distribution and ecology of freshwater sculpin, genus *Cottus*, in Oregon. Doctoral dissertation. University of Michigan, Ann Arbor, Michigan.

Brown, L. and J.F. Downhower. 1982. Summer movements of mottled sculpins, *Cottus bairdi* (Pisces: Cottidae). Copeia 1982:450-453.

Brown, L.R., S.A. Matern, and P.B. Moyle. 1995. Comparative ecology of prickly sculpin, *Cottus asper*, and coastrange sculpin, *Cottus aleuticus*, in the Eel River, California. Environmental Biology of Fishes 42:329-343.

Clary, J.R. 1972. Predation on the brown trout by the slimy sculpin. Progressive Fish-Culturist 34:91-95.

Crowl, T.A. 1989. Effects of crayfish size, orientation, and movement on the reactive distance of largemouth bass foraging in clear and turbid water. Hydrobiologia 183:133-140.

Daiber, F.C. 1956. A comparative analysis of the winter feeding habits of two benthic stream fishes. Copeia 1956:141-151.

Erman, D.C., E.D. Andrews, and M. Yoder-Williams. 1988. Effects of winter floods on fishes in the Sierra Nevada. Canadian Journal of Fisheries and Aquatic Sciences 45:2195-2200.

Fausch, K.D. and M.K. Young. 1995. Evolutionarily significant units and movement of resident stream fishes: a cautionary tale. Pages 360-370 *in* J.L. Nielsen, editor. Evolution and the aquatic ecosystem: defining unique units in population conservation. American Fisheries Society Symposium 17, Bethesda, Maryland.

Finger, T.R. 1982. Interactive segregation among three species of sculpins (*Cottus*). Copeia 1982:680-694.

Foerster, R.E. 1968. The sockeye salmon, *Oncorhynchus nerka*. Bulletin of the Fisheries Research Board of Canada 162.

Foster, J.R. 1977. Pulsed gastric lavage: an efficient method of removing the stomach contents of live fish. Progressive Fish-Culturist 39:166-169.

Freeman, M.C. and D.J. Stouder. 1989. Intraspecific interactions influence size specific depth distribution in *Cottus bairdi*. Environmental Biology of Fishes 3:231-236.

Fresh, K.L. and S.L. Schroder. 1987. Influence of the abundance, size, and yolk reserves of juvenile chum salmon (*Oncorhynchus keta*) on predation by freshwater fishes in a small coastal stream. Canadian Journal of Fisheries and Aquatic Sciences 44:236-243.

Gaudin, P. 1985. Predation exercee par le chabot (*Cottus gobio* L.) sur l'alevin de truite commune (*Salmo trutta*): taille maximale de capture des alevins pars les chabots. Hydrobiologia 122:267-270.

Ginetz, R.M and P.A. Larkin. 1976. Factors affecting rainbow trout (*Salmo gairdneri*) predation on migrant fry of sockeye salmon (*Oncorhynchus nerka*). Journal of the Fisheries Research Board of Canada 33:19-24.

Greenberg, L.A. and D.A. Holtzman. 1987. Microhabitat utilization, feeding periodicity, home range and population size of the banded sculpin, *Cottus carolinae*. Copeia 1987:19-25.

Hansel, H.C., S.D. Duke, P.T. Lofy, and G.A. Gray. 1988. Use of diagnostic bones to identify and estimate original lengths of ingested prey fishes. Transactions of the American Fisheries Society 117:55-62.

Hartman, W.L., C.W. Strickland, and D.T. Hoopes. 1962. Survival and behavior of sockeye salmon fry migrating into Brooks Lake, Alaska. Transactions of the American Fisheries Society 91:133-139.

Hill, J. and G.D. Grossman. 1987a. Effects of subcutaneous marking on stream fishes. Copeia 1987:376-380.

Hill, J. and G.D. Grossman. 1987b. Home ranges estimates for three North American stream fishes. Copeia 1987:376-380.

Hillman, T.W. 1989. Nocturnal predation by sculpins on juvenile chinook salmon and steelhead. Pages 249-264 *in* Don Chapman Consultants, Inc. Summer and winter ecology of juvenile chinook salmon and steelhead trout in the Wenatchee River, Washington. Final Report to Chelan County Public Utility District, Wenatchee, Washington.

Hoekstra, D. and J. Jansen. Non-visual feeding behavior of the mottled sculpin, *Cottus bairdi*, in Lake Michigan. Environmental Biology of Fishes 12:111-117.

Hunter, J.G. 1959. Survival and production of pink and chum salmon in a coastal stream. Journal of the Fisheries Research Board of Canada 5:448-457.

Hynes, H.B.N. 1970. The ecology of running waters. University of Toronto Press, Toronto, Ontaria.

Hyslop, E.J. 1980. Stomach contents analysis--a review of methods and their application. Journal of Fish Biology 17:411-429.

Ikusemiju, K. 1975. Aspects of the ecology and life history of the sculpin, *Cottus aleuticus* (Gilbert), in Lake Washington. Journal of Fish Biology 7:235-245.

Kirkland, L. 1962. A tagging experiment on spotted and largemouth bass using an electric shocker and Petersen disc tag. Proceedings of the Southeastern Association of Game and Fish Commissioners 16:424-432.

Krejsa, R.J. 1967. The systematics of the prickly sculpin, *Cottus asper* Richardson, a polytypic species. Part II - studies on their life history, with special reference to migration. Pacific Science 21:414-422.

Leonardsson, K., A. Bengtsson, and J. Linner. 1988. Size-selective predation by fourhorn sculpin, *Myoxocephalus quadricornis* (L.) (Pisces) on *Mesidotea entomon* (L.) (Crustacea, Isopoda). Hydrobiologia 164: 213-220.

Light, R.W., P.H. Alder, and D.E. Arnold. 1983. Evaluation of gastric lavage for stomach analyses. North American Journal of Fisheries Management 3:81-85.

Mason, J.C. and S. Machodori. 1976. Populations of sympatric sculpins, *Cottus aleuticus* and *Cottus asper*, in four adjacent salmon-producing coastal streams on Vancouver Island, B.C. Fishery Bulletin 74:131-141.

McCleave, J.D. 1964. Movement and population of the mottled sculpin (*Cottus bairdi* Girard) in a small Montana stream. Copeia 1964:506-513.

McLarney, W.O. 1967. Intra-stream movement, feeding habits, and population of the coastrange sculpin, *Cottus aleuticus*, in relation to eggs of the pink salmon *Oncorhynchus gorbuscha*, in Alaska. Doctoral dissertation. University of Michigan, East Lansing.

McPhail, J.D. and C.C. Lindsey. 1970. Freshwater fishes of northwestern Canada and Alaska. Fisheries Research Board of Canada Bulletin 173, Ottawa.

Morgan, C.R. and N.H. Ringler. 1992. Experimental manipulation of sculpin (*Cottus cognatus*) populations in a small stream. Journal of Freshwater Ecology 7:227-232.

Moyle, P.B. 1977. In defense of sculpins. Fisheries 2(1):20-23.

Newman, R.M. and T.F. Waters. 1984. Size-selective predation on *Gammarus pseudolimnaeus* by trout and sculpins. Ecology 65:1535-1545.

Northcote, T.G. 1954. Observations on the comparative ecology of two species of fish, *Cottus asper* and *Cottus rhotheus*, in British Colombia. Copeia 1954:25-28.

Pasch, R.W. and J.H. Lyford, Jr. 1972. The food habits of two species of *Cottus* occupying the same habit. Transactions of the American Fisheries Society 101:377-381.

Patten, B.G. 1962. Cottid predation upon salmon fry in a Washington stream. Transactions of the American Fisheries Society 91:427-429.

Patten, B.G. 1971a. Increased predation by the torrent sculpin, *Cottus rhotheus*, on coho salmon fry, *Oncorhynchus kisutch*, during moonlight nights. Journal of the Fisheries Research Board of Canada 28:1352-1354.

Patten, B.G. 1971b. Predation by sculpins on fall chinook salmon, *Oncorhynchus tschawytscha*, fry of hatchery origin. U.S. National Marine Fisheries Service, Special Scientific Report, Fisheries No. 621.

Pearsons, T.N., H.W. Li, and G.A. Lamberti. 1992. Influence of habitat complexity on resistance to flooding and resilience of stream fish assemblages. Transactions of the American Fisheries Society 121:427-436.

Phillips, R.W. and E.W. Claire. 1966. Intragravel movement of the reticulate sculpin, *Cottus perplexus*, and its potential as a predator on salmonid embryos. Transactions of the American Fisheries Society 95:210-212.

Rickard, N.A. 1980. Life history and population characteristics of the prickly sculpin (*Cottus asper* Richardson) in Lake Washington. Master's thesis. University of Washington, Seattle.

Ricker, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bulletin of the Fisheries Research Board of Canada 191.

Rieman, B.E., R.C. Beamesderfer, S. Vigg, and T.P. Poe. 1991. Estimated loss of juvenile salmonids to predation by northern squawfish, walleyes, and smallmouth in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:448-458.

Ringstad, N.R. And D.W. Narver. 1973. Some aspects of the ecology of two species of sculpin (*Cottus*) in a west coast Vancouver Island stream. Fisheries Research Board of Canada, Manuscript Report No. 1267.

Roger, P.B. 1971. The ecology of two species of cottids in Illiamna Lake, Alaska, and their relationship to sockeye salmon. Master's thesis. University of Washington, Seattle.

Scott, W.B. and E.J. Crossman. 1973. Freshwater fishes of Canada. Fisheries Research Board of Canada Bulletin 184, Ottawa.

Sedell, J.R., G.H. Reeves, F.R. Hauer, J.A. Stanford, and C.P. Hawkins. 1990. Role of refugia in recovery from disturbances: modern fragmented and disconnected river systems. Environmental Management 14:711-724.

Seiler, D. and L.E. Kishimoto. 1996. 1995 Cedar River sockeye salmon fry production evaluation program. Annual report, Washington Department of Fish and Wildlife, Olympia.

Shively, R.S., R.A. Tabor, R.D. Nelle, D.B. Jepsen, J.H. Petersen, S.S. Sauter, and T.P. Poe. 1991. System-wide significance of predation on juvenile salmonids in Columbia and Snake River reservoirs. Annual Report of Research, 1991, Bonneville Power Administration, Portland, Oregon.

Tabor, R.A. and J. Chan. 1996. Predation on sockeye salmon fry by piscivorous fishes in the lower Cedar River and southern Lake Washington. Miscellaneous report, U.S. Fish and Wildlife Service, Western Washington Fishery Resource Office, Olympia, Washington.

Vigg, S., T.P. Poe, L.A. Prendergast, and H.C. Hansel. 1991. Rates of consumption of juvenile salmonids and alternative prey fish by northern squawfish, walleyes, smallmouth bass, and channel catfish in John Day Reservoir, Columbia River. Transactions of the American Fisheries Society 120:421-438.

Vinyard, G.L. and W.J. O'Brien. 1976. Effects of light and turbidity on the reactive distance of bluegill (*Lepomis macrochirus*). Journal of the Fisheries Research Board of Canada 33:2845-2849.

Wiggins, W.D., G.P. Ruppert, R.R. Smith, L.L. Reed, L.E. Hubbard, and M.L. Courts. 1996. Water resources data, Washington, water year 1995. Water-data report WA-95-1, U.S. Geological Survey, Tacoma, Washington.

Wydoski, R.S. and R.R. Whitney. 1979. Inland fishes of Washington. University of Washington Press, Seattle.

Table 1.--Location and distance of beach seining sites and electrofishing transects used to collect piscivorous fishes in the lower 1.7 km of Cedar River. The river mouth is located at the downstream end of the lower Boeing Bridge. Section: 1 = lower, 2 = middle, 3 = upper.

GEAR TYPE Site/transect	Location	Distance from river mouth (m)	Distance sampled (m)	Section
BEACH SEINING				
1	Right bank	325 - 425	100	1
2	Right bank	540 - 630	90	2
3	Right bank	650 - 740	90	2
BOAT ELECTROFISHING				
1	Lower Boeing Bridge (downstream)	0	78	1
2	Lower Boeing Bridge (upstream)	10 - 38	102	1
3	Right bank	38 - 338	300	1
4	Left bank	38 - 438	400	1
BACKPACK ELECTROFISHING				
5	Right bank side channel	348 - 420	72	1
6	Right bank	428 - 608	180	2
7	Left bank	541 - 698	157	2
8	Right bank	688 - 762	74	2
9	Left bank side channel (upper Boeing Br.)	1128 -1229	101	3
10	Right bank	1370 -1700	330	3

Table 2. Habitat characterization of the lower Cedar River sampling transects (1-10). Percent bulkhead and gabion under Instream structure, represent the percentage of the transect shoreline with these structures.

Transect number	Average sampling depth (m)	Substate composition		Overhanging vegetation (%)	Instream structure / cover
		type	%		
1	1.80	silt	0	5	bridge supports, woody debris
		sand	50		
		gravel	40		
		cobble	0		
		boulder	10		
2	1.80	silt	0	5	bridge supports, woody debris
		sand	50		
		gravel	50		
		cobble	0		
		boulder	0		
3	1.58	silt	9	10	35 % bulkhead, woody debris pile
		sand	1		
		gravel	4		
		cobble	34		
		boulder	52		
4	1.47	silt	27	11	100 % bulkhead, small woody debris
		sand	0		
		gravel	3		
		cobble	54		
		boulder	16		
5	0.69	silt	60	7	20 % gabion, small woody debris
		sand	14		
		gravel	14		
		cobble	12		
		boulder	0		
6	0.61	silt	11	70	20 % bulkhead, small woody debris
		sand	26		
		gravel	60		
		cobble	0		
		boulder	3		
7	0.64	silt	9	44	56 % bulkhead, small woody debris
		sand	2		
		gravel	89		
		cobble	0		
		boulder	0		
8	0.50	silt	0	10	woody debris pile, submerged grasses
		sand	40		
		gravel	60		
		cobble	0		
		boulder	0		
9	0.25	silt	11	17	bridge structure (shade), woody debris jam
		sand	0		
		gravel	66		
		cobble	23		
		boulder	0		
10	0.20	silt	1	71	small woody debris
		sand	29		
		gravel	68		
		cobble	2		
		boulder	0		

Table 3. Modified Schnabel population estimates of cottids > 59 mm TL in the lower Cedar River, April-June, 1996. CI = 95% confidence interval. Population estimates represent a combined estimate of four species: prickly, coastrange, torrent, and reticulate sculpin.

Section	Site	Date	Number caught C	Number of recaptures R	Number marked at large M	Number marked (less removals)	N	Lower CI	Upper CI
Lower	3,4,5	April 2-4	257	0	0	257			
		April 5	150	13	257	51			
		April 10	135	13	308	--			
		Total		26		308	2968	2109	4714
Middle	6	May 1	32	0	0	32			
		May 7	59	1	32	58			
		May 29	71	3	90	65			
		June 3	80	7	155	--			
		Total		11		155	1723	1050	3829
Middle	7	May 1	26	0	0	26			
		May 7	55	1	26	54			
		May 29	85	7	80	77			
		June 3	85	9	157	--			
		Total		17		157	1199	793	2179
Middle	8	May 1	16	0	0	16			
		May 14	36	1	16	34			
		May 29	59	1	50	57			
		June 3	58	5	107	--			
		Total		7		107	1217	676	3476
Upper	9	May 7	21	0	0	21			
		May 14	10	1	21	9			
		June 3	29	1	50	28			
		June 4	30	3	58	--			
		Total		5		58	567	291	2125
Upper	10	May 1	26	0	0	26			
		May 14	51	1	26	50			
		June 4	76	5	76	70			
		June 5	66	9	146	--			
		Total		15		146	1046	675	1993

Table 4. Population and shoreline density estimates of four species of cottids in the lower Cedar River, April-June, 1996. Initially, the four species were combined to calculate a cottid population estimate for each transect. Population estimates for each species were based on the percent of catch for each transect. Population estimates are for cottids > 59 mm TL. Sc = sculpin; CI = 95% confidence interval.

Section	Site	Cottid species	Percent of catch	N	Length of transect (m)	Number/m	Lower CI	Upper CI
Lower	3,4,5	Prickly Sc.	94	2776	772	3.60		
		Torrent Sc.	3	99	772	0.13		
		Reticulate Sc.	0	0	772	0.00		
		Coastrange Sc.	3	93	772	0.12		
		Total	100	2968	772	3.84	2.73	6.11
Middle	6	Prickly Sc.	70	1206	180	6.70		
		Torrent Sc.	16	279	180	1.55		
		Reticulate Sc.	9	150	180	0.83		
		Coastrange Sc.	5	89	180	0.49		
		Total	100	1723	180	9.57	5.83	21.27
Middle	7	Prickly Sc.	63	759	157	4.83		
		Torrent Sc.	11	131	157	0.83		
		Reticulate Sc.	21	246	157	1.57		
		Coastrange Sc.	5	62	157	0.40		
		Total	100	1199	157	7.63	5.05	13.88
Middle	8	Prickly Sc.	52	635	74	8.58		
		Torrent Sc.	28	338	74	4.57		
		Reticulate Sc.	19	236	74	3.20		
		Coastrange Sc.	1	7	74	0.09		
		Total	100	1217	74	16.44	9.13	46.97
Upper	9	Prickly Sc.	52	296	101	2.93		
		Torrent Sc.	30	170	101	1.68		
		Reticulate Sc.	16	88	101	0.87		
		Coastrange Sc.	2	13	101	0.12		
		Total	100	567	101	5.61	2.88	21.04
Upper	10	Prickly Sc.	31	326	330	0.99		
		Torrent Sc.	45	475	330	1.44		
		Reticulate Sc.	20	213	330	0.65		
		Coastrange Sc.	3	32	330	0.10		
		Total	100	1046	330	3.17	2.05	6.04

Table 5.--Salmonid fry and other prey fish consumed by predatory fish from beach seining sites on the lower Cedar River, March 29 and June 5, 1996. Fry per stomach includes both sockeye salmon fry and unidentified salmonid fry. Sock. fry = sockeye salmon fry, Uni. sal. fry = unidentified salmonid fry which are similar in size as sockeye salmon fry, FO = frequency of occurrence (%), Max.= maximum number of salmonid fry observed in a stomach, Oth. sal.= other salmonids, Ad. smelt = adult longfin smelt, Lar. fish = larval fish, Oth. fish = other fish.

Predators			Salmonid fry consumed					Other fish consumed			
Date Location Species	N	% Empty stom.	Sock. fry	Uni. sal. fry	Fry per stom.	FO	Max.	Oth. sal.	Ad. smelt	Lar. fish	Oth. fish
March 20											
Lower section											
Cutthroat trout	1	100	0	0	0	0	0	0	0	0	0
Coastrange scul.	25	4	5	1	0.24	12	3	0	0	0	0
Prickly sculpin	24	0	31	7	1.58	63	8	0	0	0	0
Torrent sculpin	6	0	8	0	1.33	67	3	0	0	0	1
Middle section											
Coastrange scul.	22	5	0	0	0	0	0	0	0	0	0
Torrent sculpin	1	0	0	0	0	0	0	0	0	0	0
June 5											
Lower section											
Cutthroat trout	2	0	0	0	0	0	0	0	0	18	0
Hatchery trout	1	0	0	0	0	0	0	0	0	9	0
Coastrange scul.	7	29	0	0	0	0	0	0	0	2	0
Prickly sculpin	17	12	0	0	0	0	0	0	0	2	0
Torrent sculpin	2	0	0	0	0	0	0	0	0	1	0
Middle section											
Coastrange scul.	14	7	0	0	0	0	0	0	0	0	0
Prickly sculpin	4	25	0	0	0	0	0	0	0	0	3
Torrent sculpin	2	0	0	0	0	0	0	0	0	0	0

Table 6.--Salmonid fry and other prey fish consumed by predatory fish in the lower Cedar River, February-June, 1996. Predatory fish were collected with boat and backpack electrofishing equipment. Column headings are described in Table 3.

Predators			Salmonid fry consumed					Other fish consumed			
Date Location Species	N	% Empty stom.	Sock. fry	Uni. sal. fry	Fry per stom.	FO	Max.	Oth. sal.	Ad. smelt	Lar. fish	Oth. fish
February-March											
Lower section											
Cutthroat trout	3	67	4	0	1.33	33	4	0	1	0	0
Rainbow trout	3	33	0	0	0	0	0	0	8	0	1
Coho salmon	1	0	0	0	0	0	0	0	0	0	0
Mountain whitefish	2	0	0	0	0	0	0	0	0	0	0
Coastrange scul.	3	0	0	0	0	0	0	0	0	0	1
Prickly sculpin	120	16	113	5	0.98	31	12	2	36	0	0
Reticulate scul.	1	0	0	1	1.00	100	1	0	0	0	0
Torrent sculpin	2	0	0	0	0	0	0	0	0	0	0
Middle section											
Cutthroat trout	2	0	0	0	0	0	0	0	0	0	0
Rainbow trout	4	0	0	0	0	0	0	0	1	0	1
Coho salmon	2	50	0	0	0	0	0	0	0	0	0
Coastrange scul.	4	25	0	0	0	0	0	0	0	0	0
Prickly sculpin	9	22	1	0	0.11	11	1	0	0	0	0
Upper section											
Cutthroat trout	8	13	8	1	1.13	33	3	0	1	0	0
Rainbow trout	4	0	3	0	0.75	25	3	0	1	0	0
Coho salmon	3	0	5	2	2.33	67	5	0	0	0	2
Coastrange scul.	2	0	0	0	0	0	0	0	0	0	1
April-June											
Lower section											
Cutthroat trout	26	8	2	2	0.15	4	4	0	4	169	1
Rainbow trout	8	25	0	0	0	0	0	0	0	0	1
Hatchery trout	3	0	0	0	0	0	0	0	0	0	0
Coho salmon	14	0	0	0	0	0	0	0	0	9	0
Chinook salmon	3	0	0	0	0	0	0	0	0	5	0
Mountain whitefish	3	33	0	0	0	0	0	0	0	0	0
Smallmouth bass	2	0	0	0	0	0	0	0	0	0	4
Yellow perch	1	100	0	0	0	0	0	0	0	0	0
Coastrange scul.	4	0	0	0	0	0	0	0	0	0	0
Prickly sculpin	131	15	4	0	0.03	3	1	0	15	2	18
Torrent sculpin	6	17	1	0	0.17	17	1	0	0	0	1
Middle section											
Cutthroat trout	1	0	0	1	1.00	100	1	0	0	0	0
Coho salmon	2	0	0	0	0	0	0	0	0	0	0
Smallmouth bass	1	0	0	0	0	0	0	0	0	0	0
Yellow perch	1	0	0	0	0	0	0	0	0	0	0
Coastrange scul.	7	22	0	0	0	0	0	0	0	0	0
Prickly sculpin	26	19	0	0	0	0	0	0	0	1	3
Reticulate scul.	7	29	0	0	0	0	0	0	0	0	0
Torrent sculpin	3	0	0	0	0	0	0	0	0	0	0

Table 6.--continued.

Predators			Salmonid fry consumed					Other fish consumed			
Date Species	N	% Empty stom.	Sock. fry	Uni. sal. fry	Fry per stom.	FO	Max.	Oth. sal.	Ad. smelt	Lar. fish	Oth. fish
Upper section											
Cutthroat trout	3	0	1	0	0.33	33	1	0	0	12	0
Coho salmon	8	0	2	0	0.25	25	1	0	0	73	0
Brown Bullhead	1	0	0	0	0	0	0	0	0	0	0
Coastrange scul.	6	17	0	0	0	0	0	0	0	0	0
Prickly sculpin	25	8	0	3	0.12	4	3	0	0	1	6
Reticulate scul.	4	0	0	0	0	0	0	0	0	0	0
Torrent sculpin	22	0	1	1	0.09	5	2	0	0	0	5

Table 7.-- Number of salmonid fry, longfin smelt, and other prey fish consumed by six size categories of prickly sculpin in the lower Cedar River, February-June, 1996. Prickly sculpin were collected with electrofishing equipment and beach sienes. Column headings are described in Table 3.

Prickly Sculpin			Salmonid fry consumed					Longfin smelt consumed				Other fish consumed		
Date Size category (mm)	N	% Empty stom.	Sockeye fry	Uni. sal. fry	Fry per stomach	FO	Max.	Smelt	Smelt per stomach	FO	Max.	Sculpin	Lamprey	Other
March (hatchery releases)														
50-74	27	4	18	3	0.78	52	4	0	0	0	0	0	0	0
75-99	25	8	43	7	2.00	56	9	0	0	0	0	0	0	1
100-124	40	15	31	0	0.78	20	10	5	0.13	10	2	5	0	2
125-149	39	23	51	2	1.36	41	12	14	0.36	33	2	4	0	2
150-174	12	17	0	0	0	0	0	9	0.75	58	2	0	0	2
175-225	10	10	2	0	0.20	20	2	8	0.80	70	2	2	0	0
April														
50-74	8	0	1	3	0.50	25	2	0	0	0	0	0	0	0
75-99	23	13	1	0	0.04	4	1	0	0	0	0	0	0	2
100-124	28	28	2	0	0.07	7	2	2	0.07	4	1	2	0	1
125-149	23	43	0	0	0	0	0	10	0.43	35	2	2	0	0
150-174	8	13	0	0	0	0	0	2	0.25	25	1	1	0	2
175-225	1	0	0	0	0	0	0	1	1.00	100	1	0	0	0
May-June														
50-74	18	6	0	0	0	0	0	0	0	0	0	0	0	0
75-99	35	11	0	0	0	0	0	0	0	0	0	1	0	1
100-124	26	4	0	0	0	0	0	0	0	0	0	1	2	3
125-149	19	11	0	0	0	0	0	0	0	0	0	4	3	0
150-174	12	8	0	0	0	0	0	0	0	0	0	3	3	2
175-225	2	0	0	0	0	0	0	0	0	0	0	0	2	1

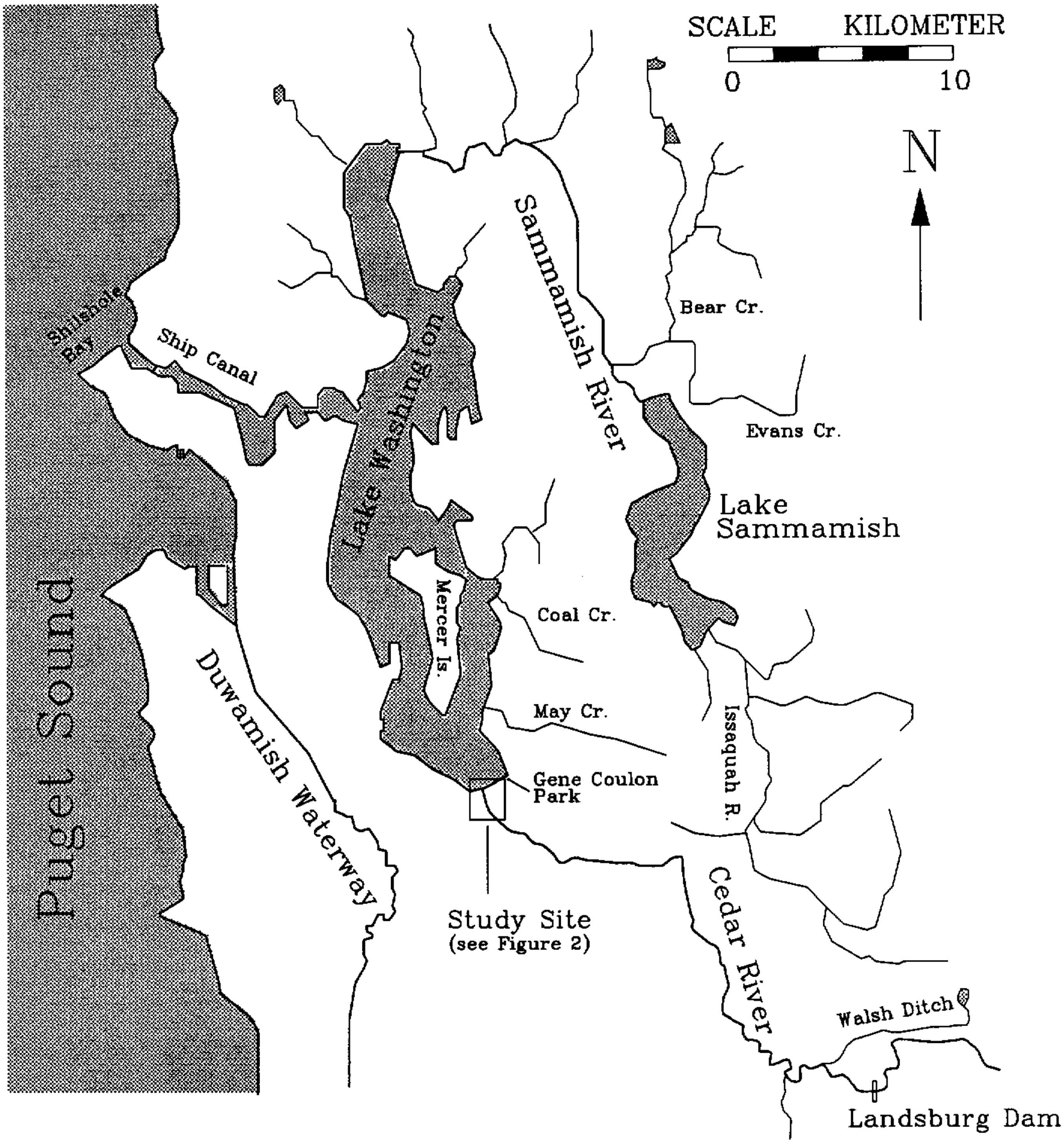


Figure 1.-- Map of Lake Washington drainage basin and location of study site.

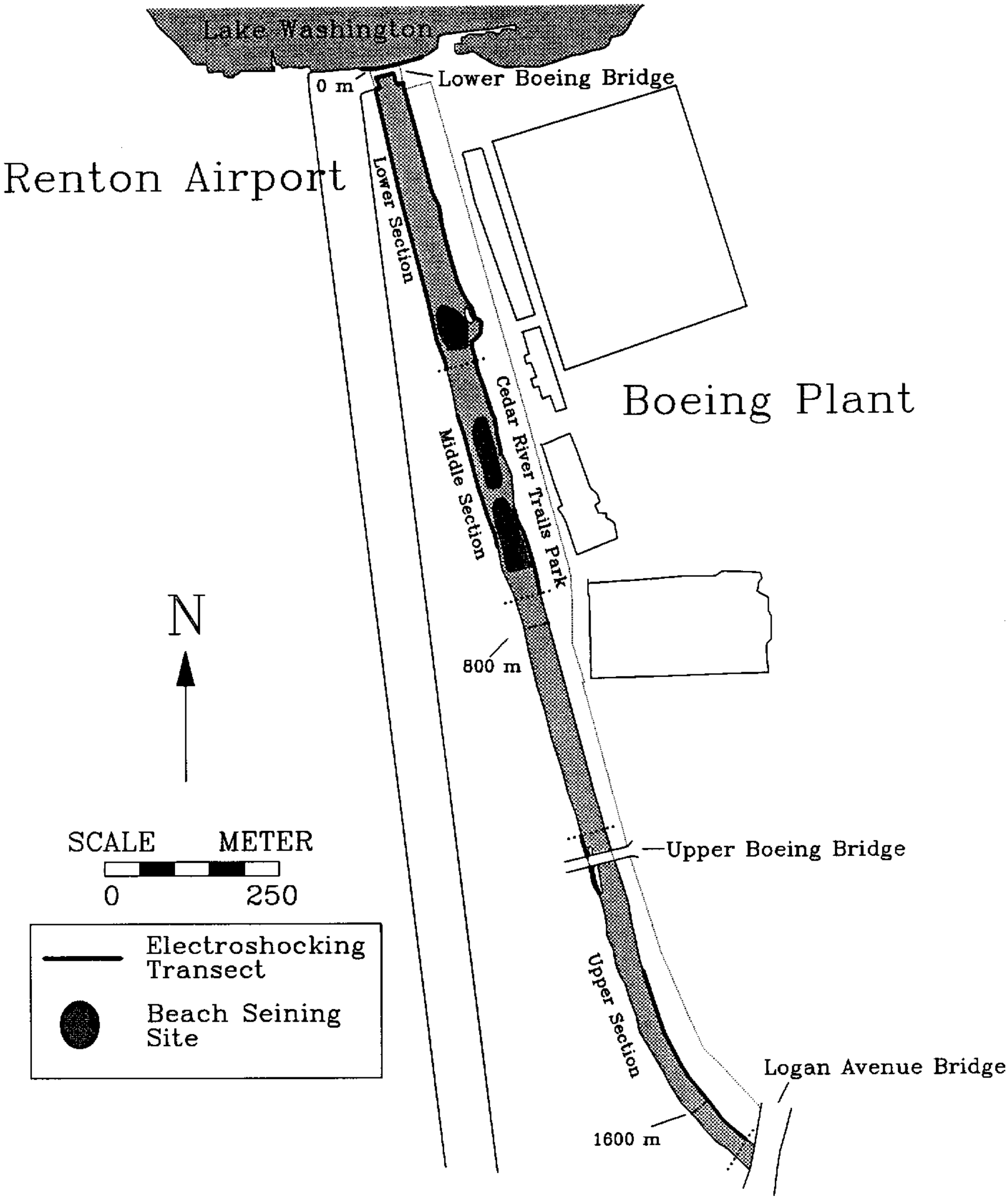


Figure 2.-- Sample sites used to collect predatory fishes in the lower Cedar River. Distances correspond to Table 1.

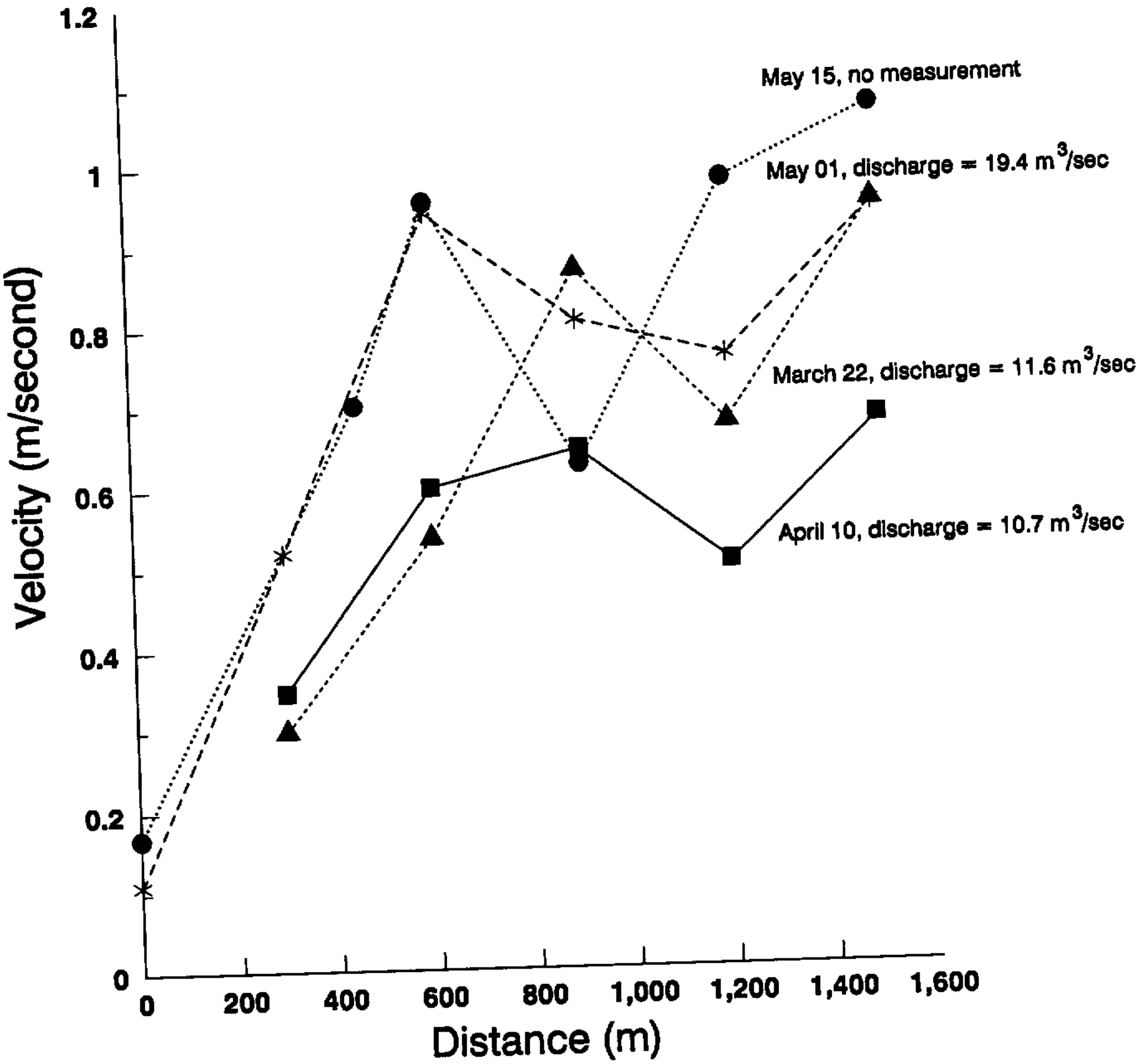


Figure 3.-- Mid-channel velocities measured at intervals between 0-1,500 m upstream from the mouth of the Cedar River. Measurements were taken approximately near the center of the channel. Data were adapted from Army Corps of Engineers velocity measurements taken during the 1996 longfin smelt spawning surveys.

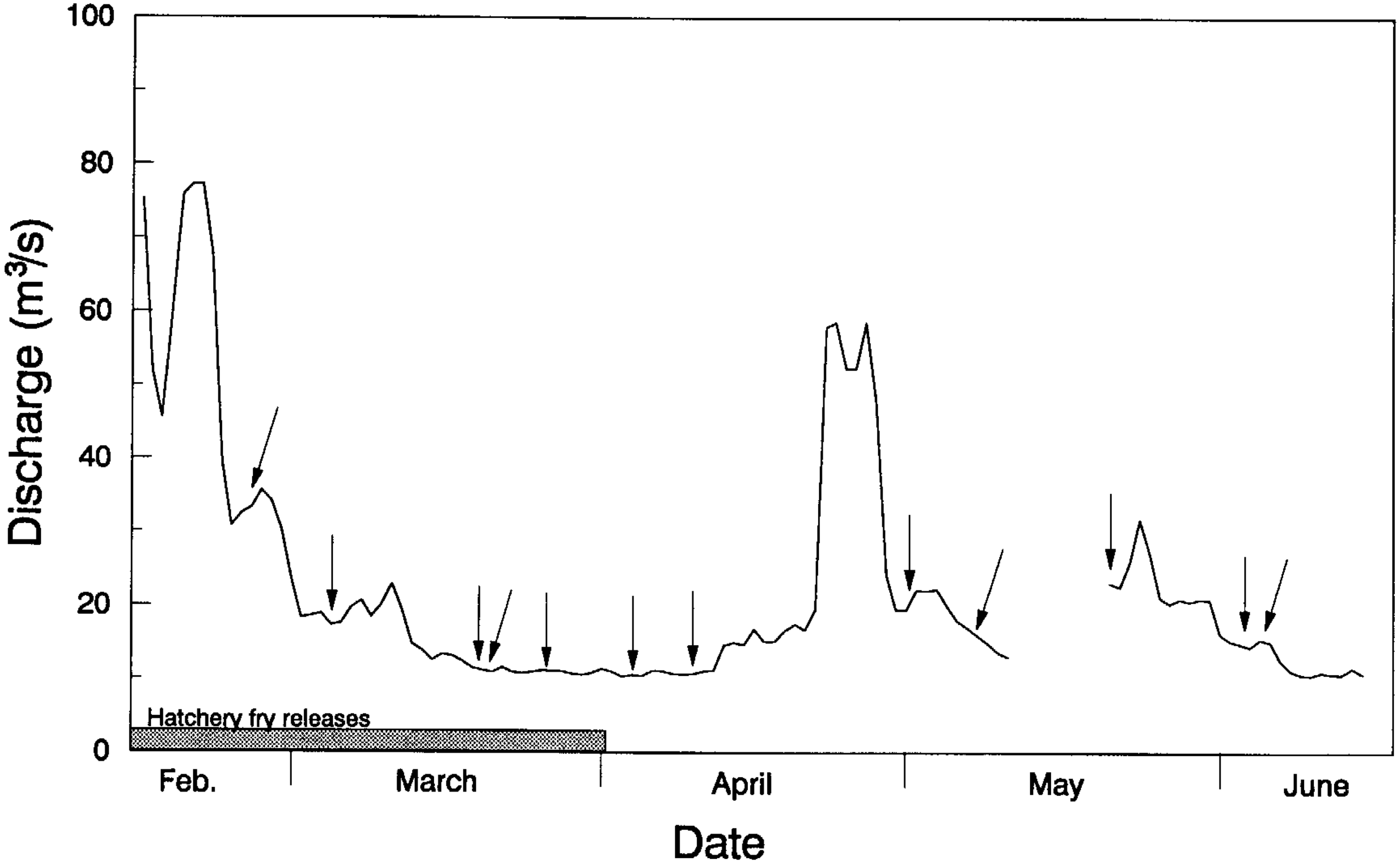


Figure 4.-- Daily discharge levels (m^3/s) of the Cedar River at the USGS Renton gauge (river kilometer 2.6) for February 15-June 15, 1996 (USGS, unpublished data). Arrows indicate dates stomach samples were taken. The time period in which hatchery sockeye salmon fry were released is shown. Releases typically occurred two-three times per week. During the hatchery release period, predatory fishes were collected shortly after the sockeye salmon fry had emigrated past the lower Cedar River.

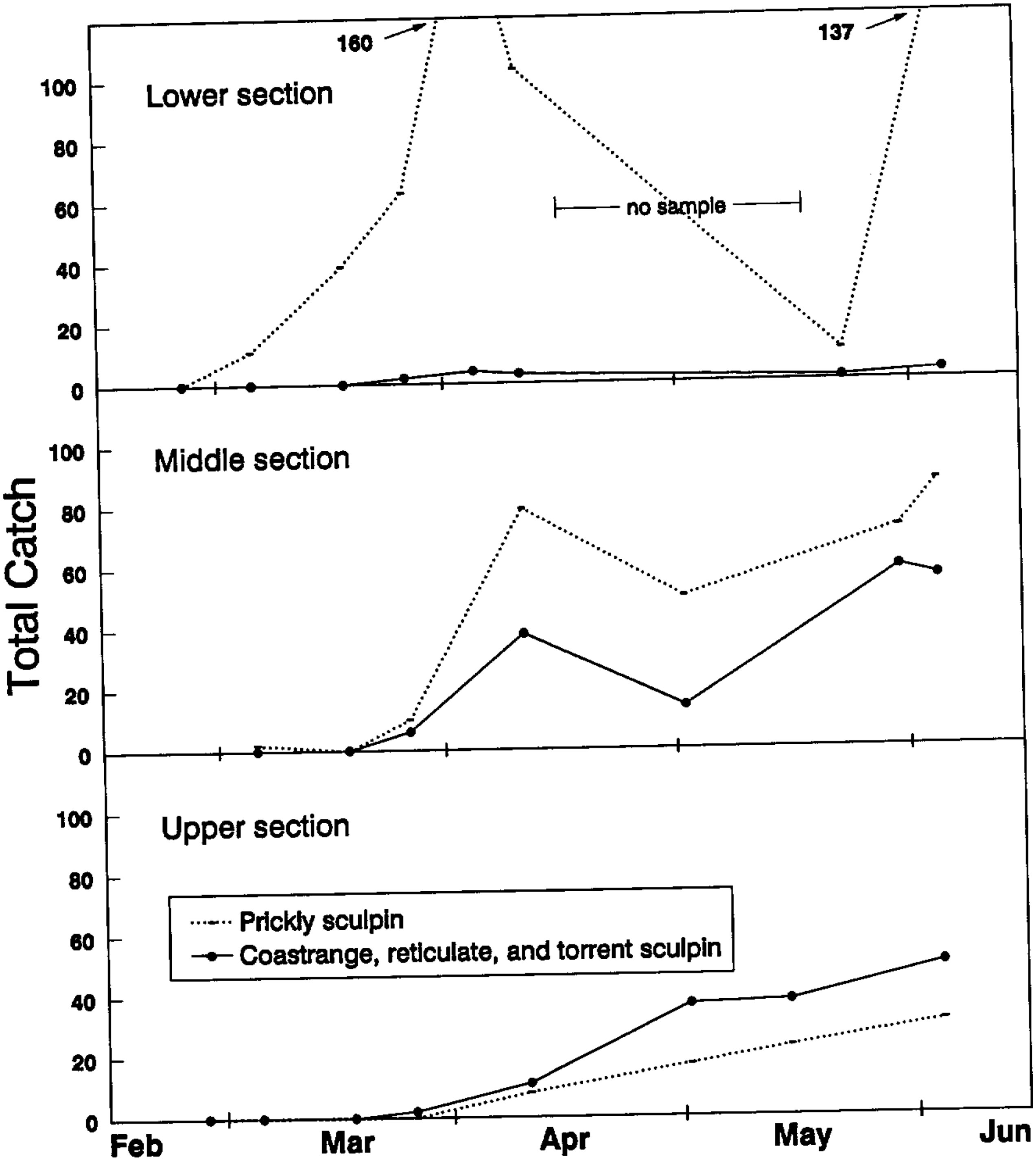


Figure 5.-- Total catch of cottids (≥ 60 mm FL) collected by electrofishing in the three sections of the lower Cedar River, February-June, 1996. Values represent the total catch of three electrofishing transects for each date in the lower section and the total catch of two transects for each date in the middle and upper sections. Most of the lower section was sampled with a boat electrofisher, while a backpack electrofisher was used in the middle and upper sections.

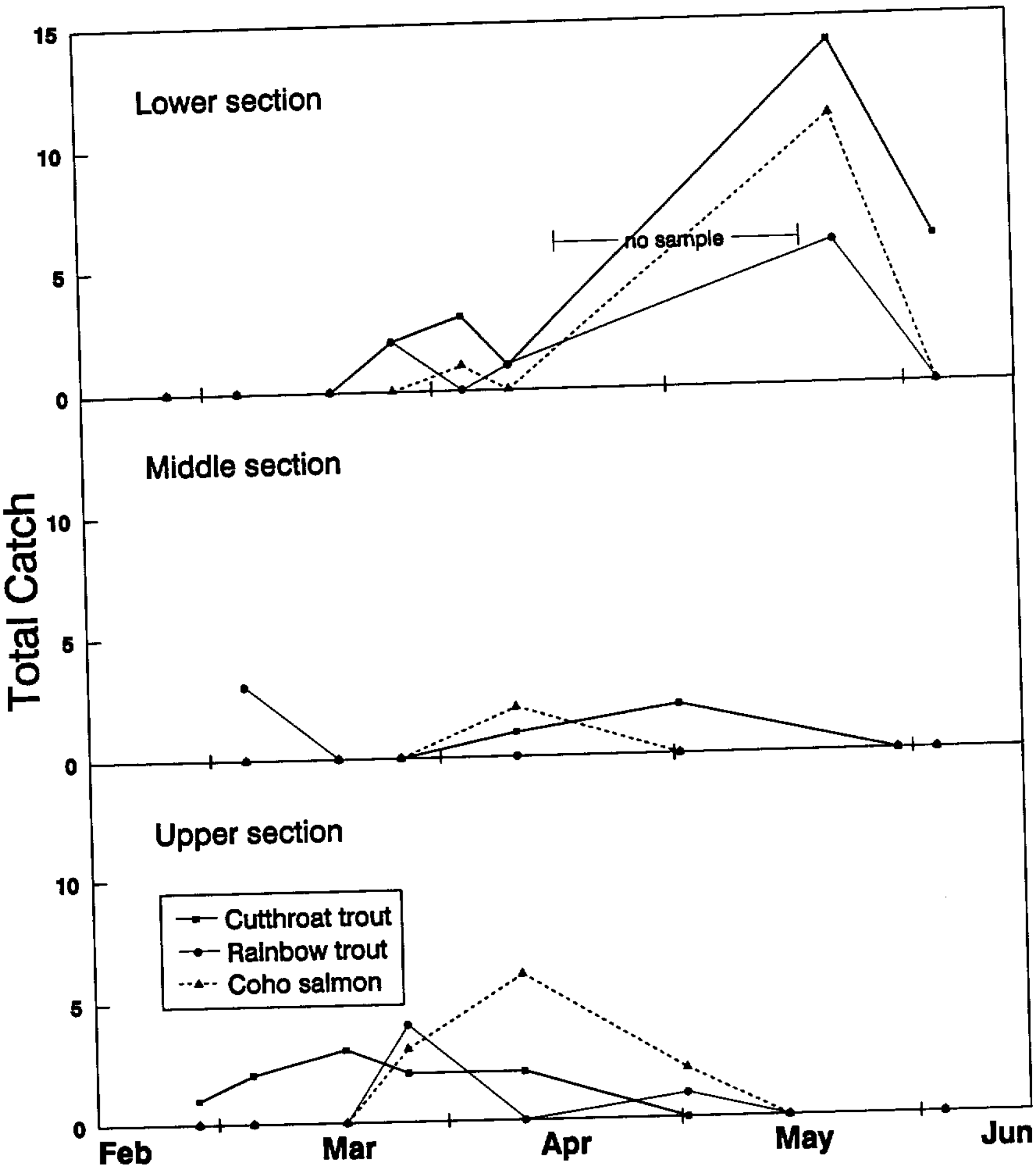


Figure 6.-- Total catch of salmonid predators (≥ 70 mm FL) collected by electrofishing in the three sections of the lower Cedar River, February-June, 1996. Values represent the total catch of three electroshocking transects for each date in the lower section and the total catch of two transects for each date in the middle and upper sections. Most of the lower section was sampled with a boat electrofisher, while a backpack electrofisher was used in the middle and upper sections.

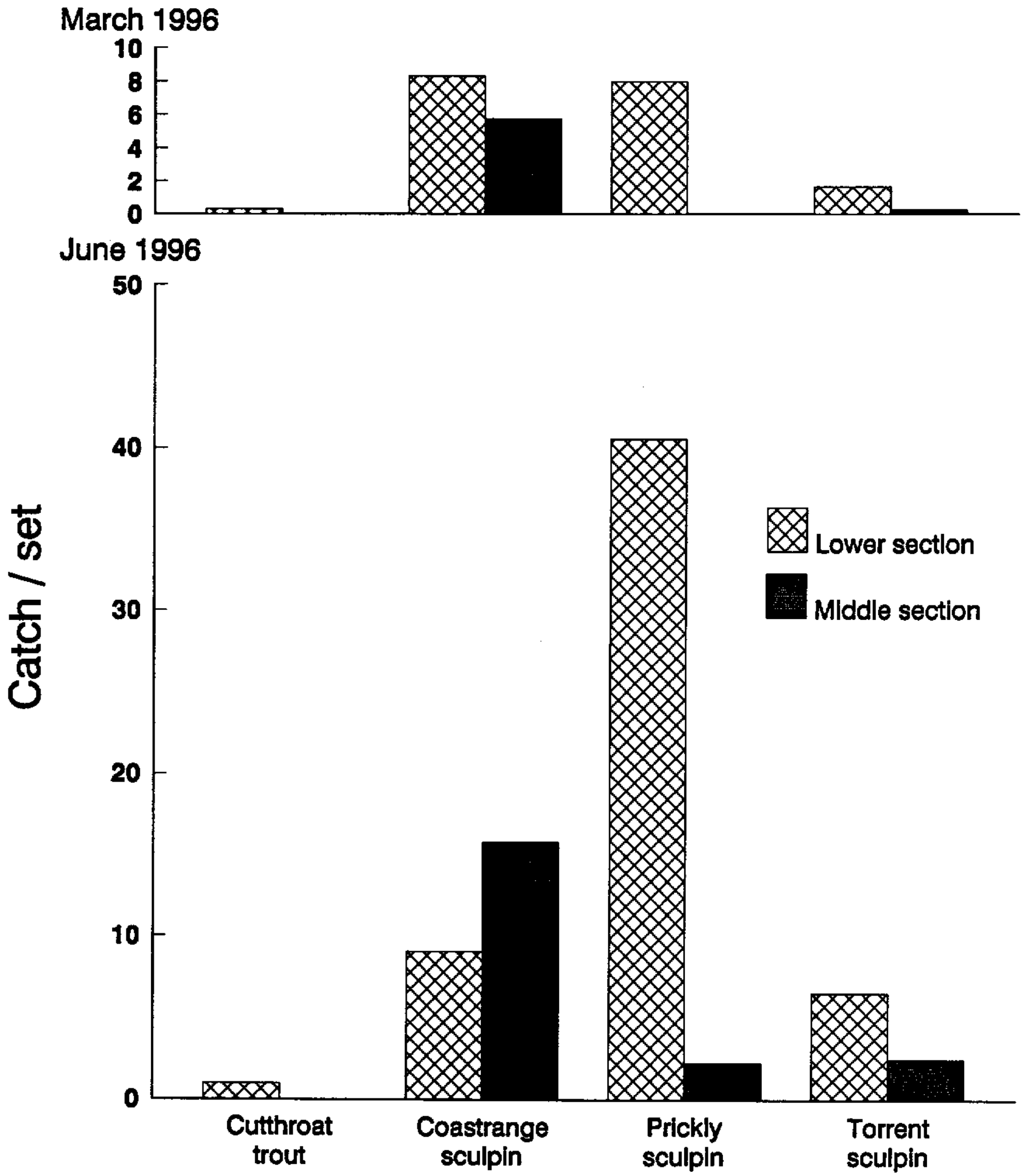


Figure 7.-- Beach seining catch (number/set) of predatory fishes from two sections of the lower Cedar River, March and June, 1996. Values represent the catch per set from two night-sampling periods.

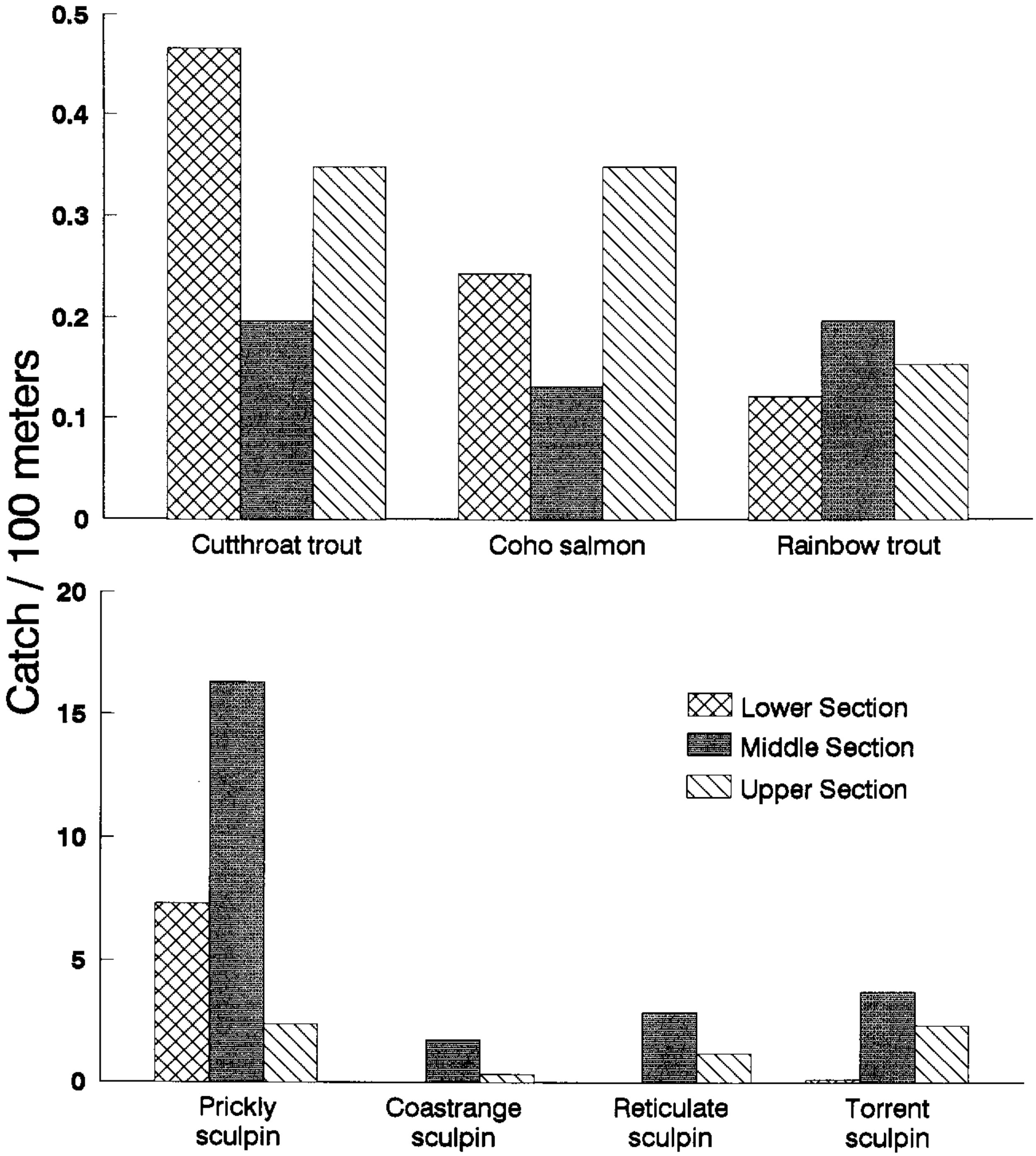


Figure 8.-- Electrofishing catch (number/100 m) of predatory fishes from three sections of the lower Cedar River, March-June, 1996. Values represent the catch per distance (100 m) shocked from six night-sampling periods. Most of the lower section was sampled with a boat electrofisher, while a backpack electrofisher was used in the middle and upper sections.

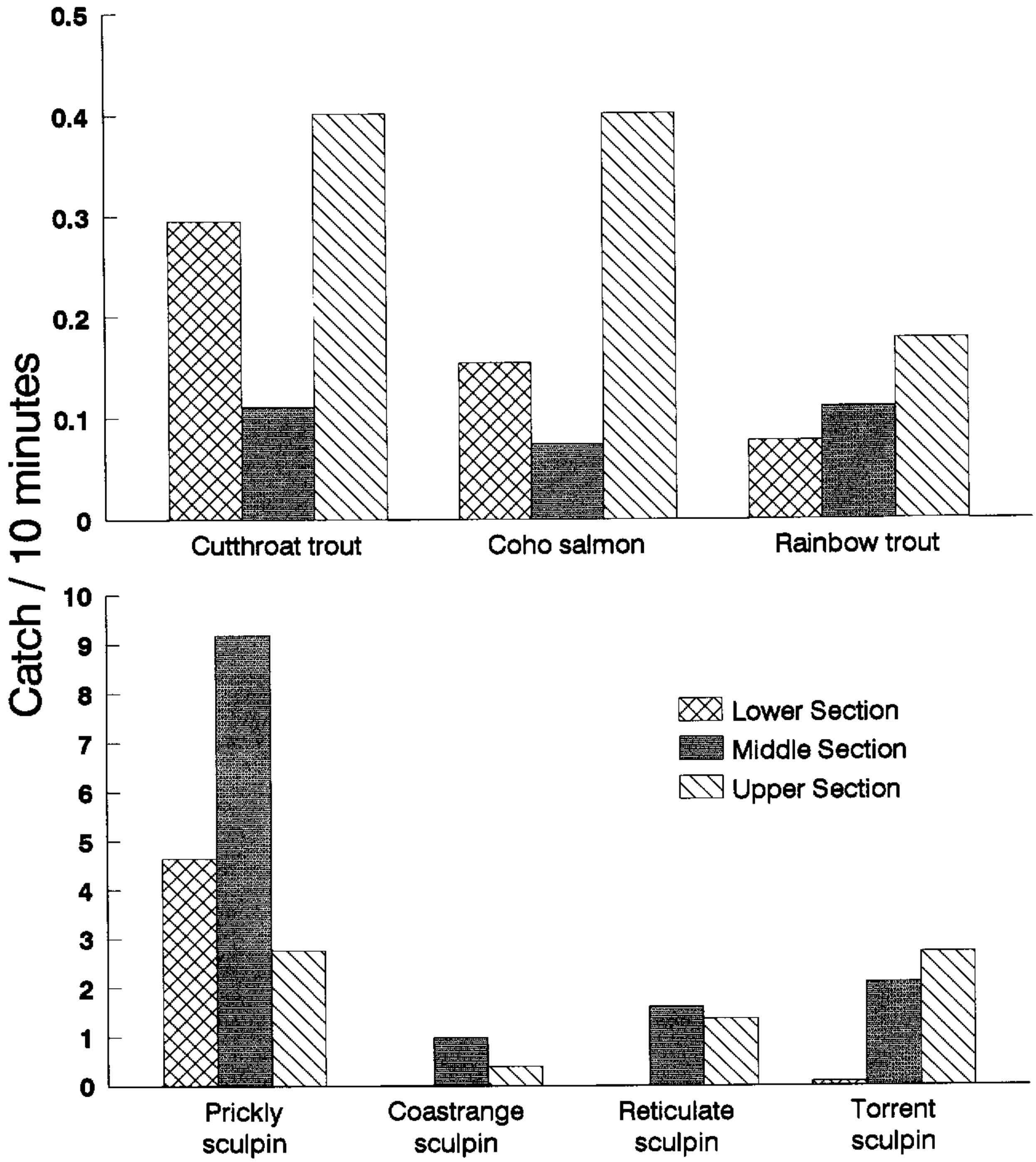


Figure 9.-- Electrofishing catch (number/10 min) of predatory fishes from three sections of the lower Cedar River, March-June, 1996. Values represent the catch per amount of time (10 min) shocked from six night-sampling periods. Most of the lower section was sampled with a boat electrofisher, while a backpack electrofisher was used in the middle and upper sections.

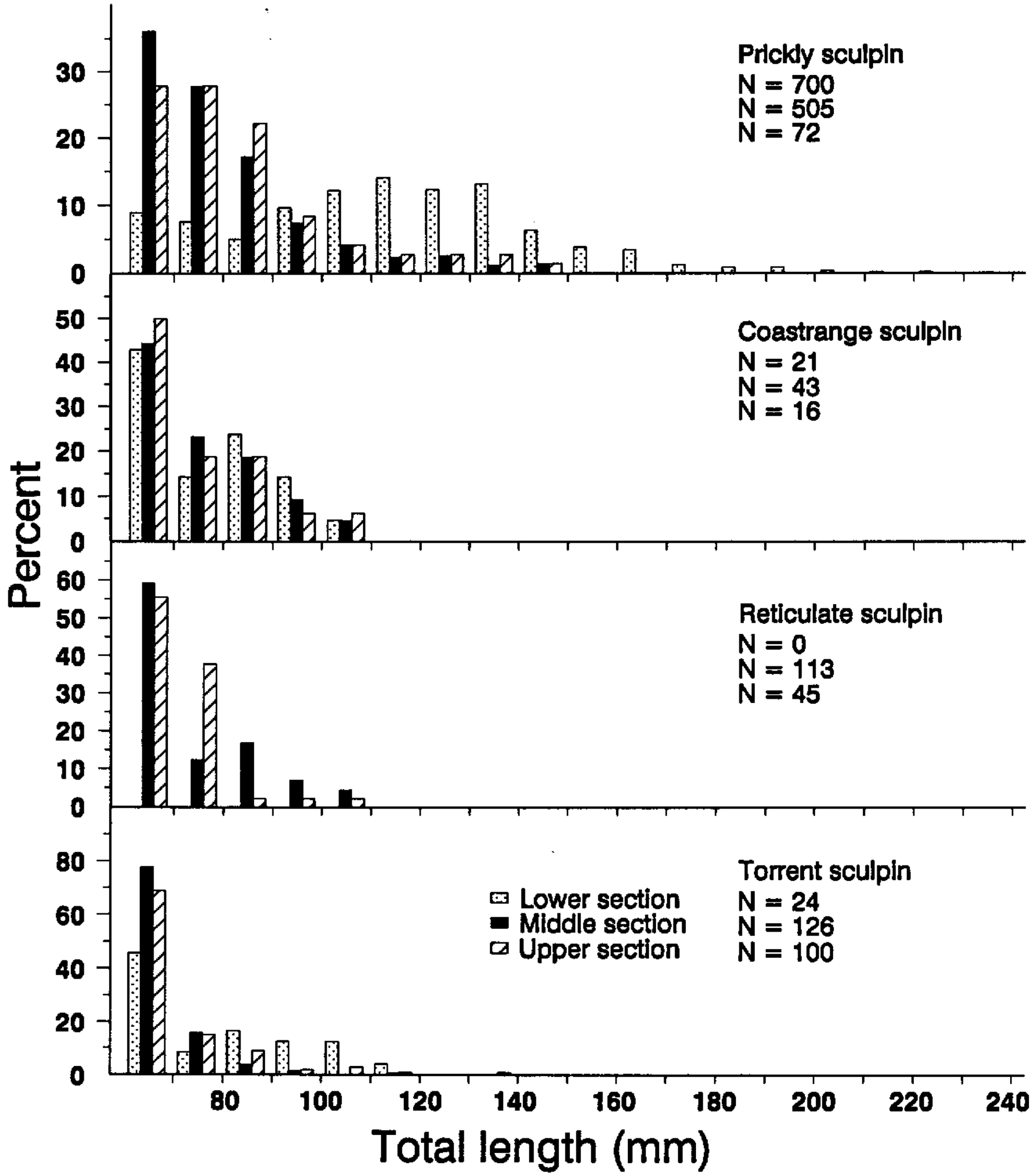


Figure 10.-- Length frequencies of cottids ≥ 60 mm TL collected by electrofishing in the three sections of the lower Cedar River, February-June, 1996. Smaller fish are not included because they may have been overlooked during electrofishing.

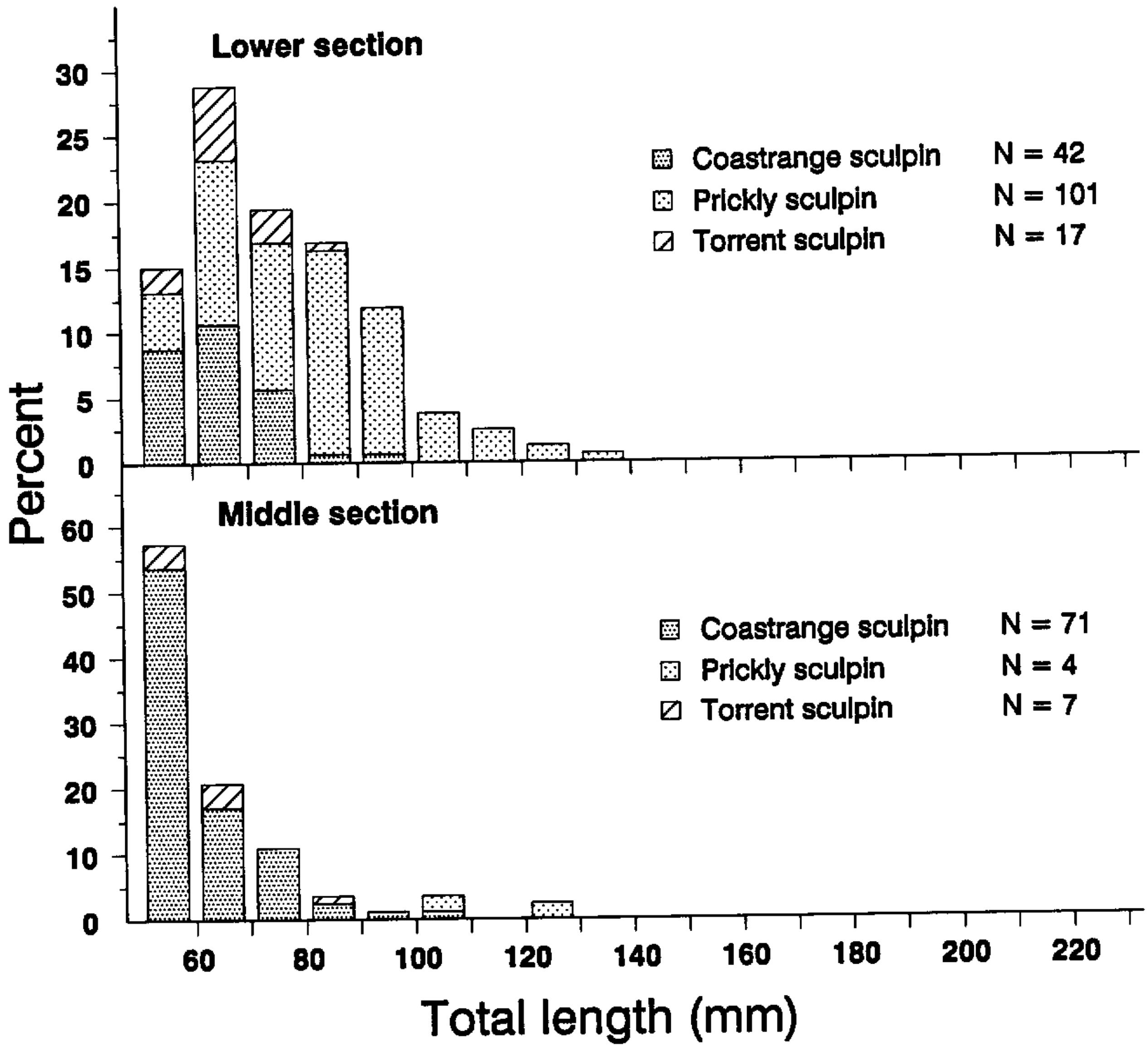


Figure 11.-- Length frequencies of cottids ≥ 50 mm TL collected by beach seining in the lower and middle sections of the lower Cedar River, March and June, 1996.

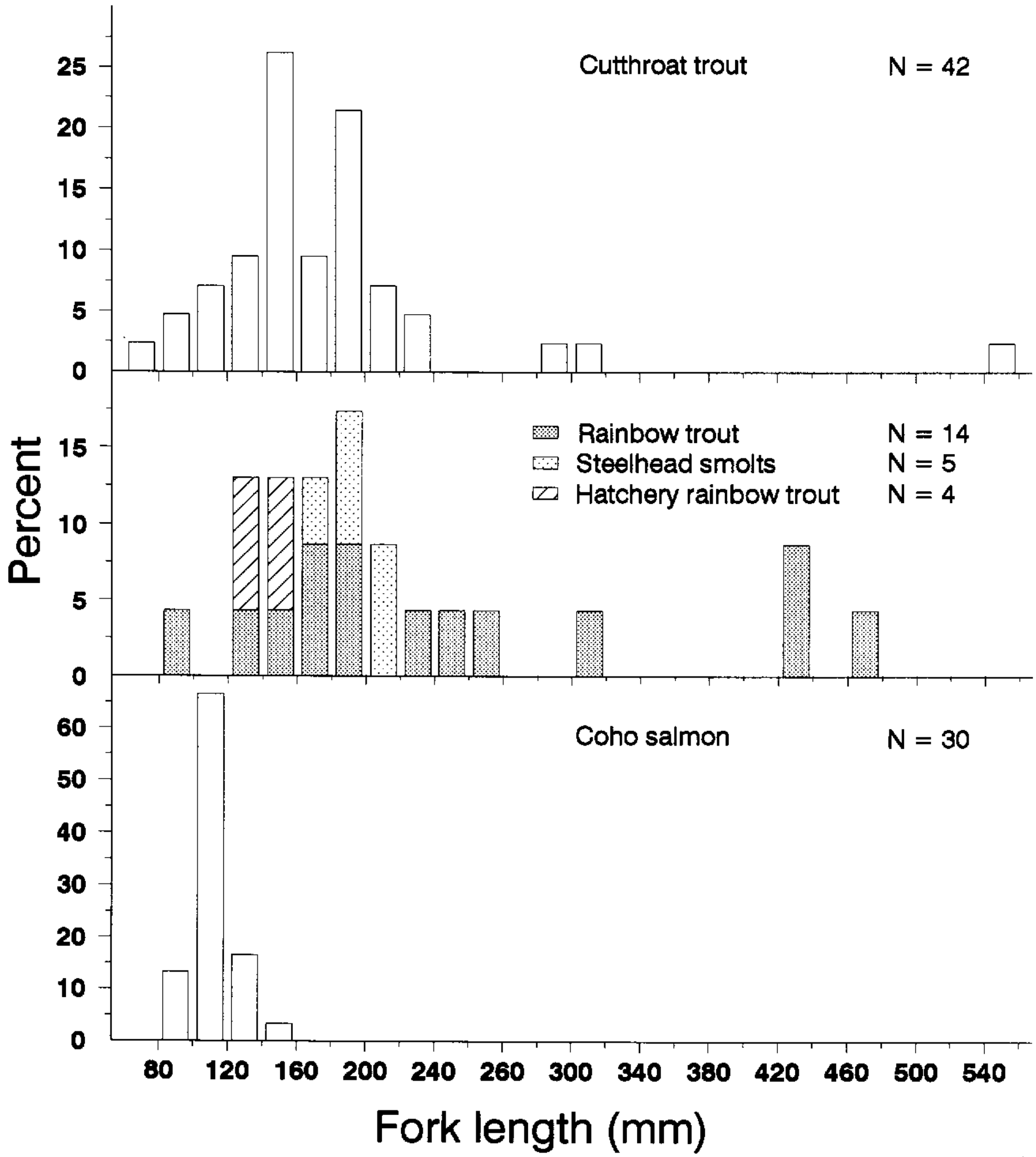


Figure 12.-- Length frequencies of salmonid predators ≥ 70 mm FL collected in the lower Cedar River, February-June, 1996. Fish were collected by electrofishing. Rainbow trout, steelhead smolts, and hatchery rainbow trout were combined, due to the qualitative assessment in distinguishing the types.

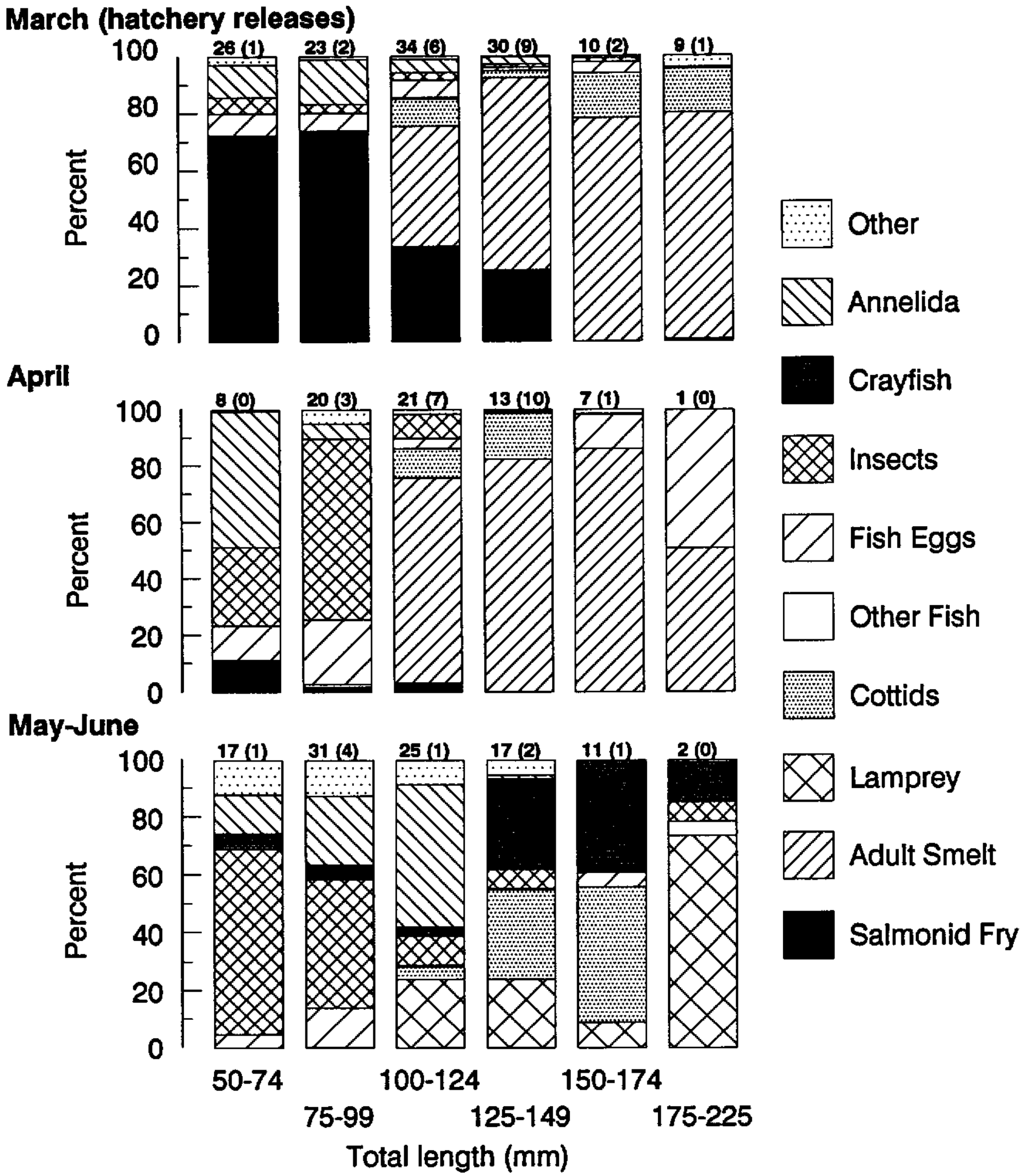


Figure 13.-- Composition (percent by weight) of ingested food for six size categories of prickly sculpin in the lower Cedar River, 1996. Percents were calculated from pooled data. Number of predator stomachs that contained prey items is given above the graph; the number of fish with empty stomachs is in parentheses.

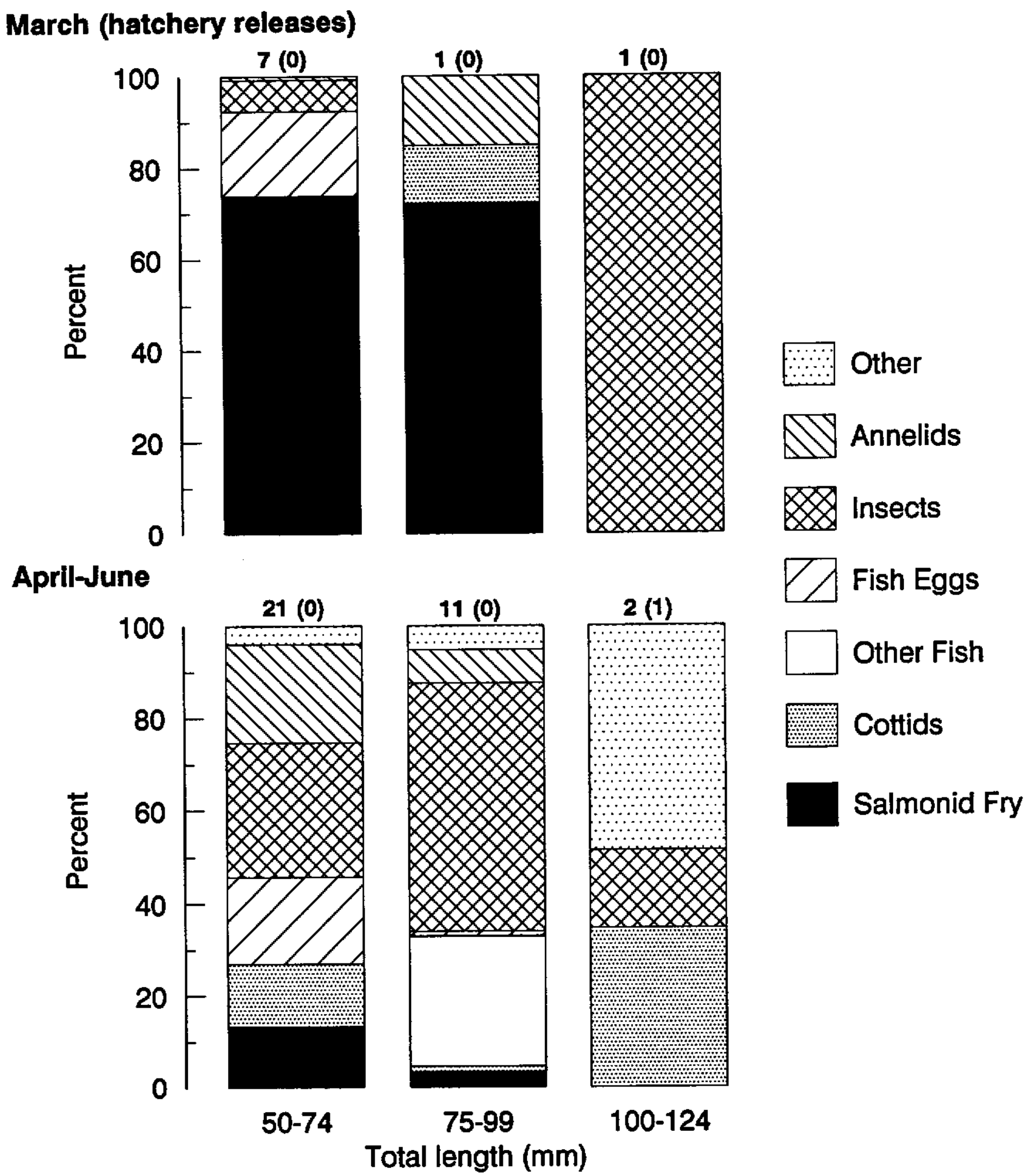


Figure 14.-- Composition (percent by weight) of ingested food for three size categories of torrent sculpin in the lower Cedar River, 1996. Percents were calculated from pooled data. Number of predator stomachs that contained prey items is given above the graph; the number of fish with empty stomachs is in parentheses.

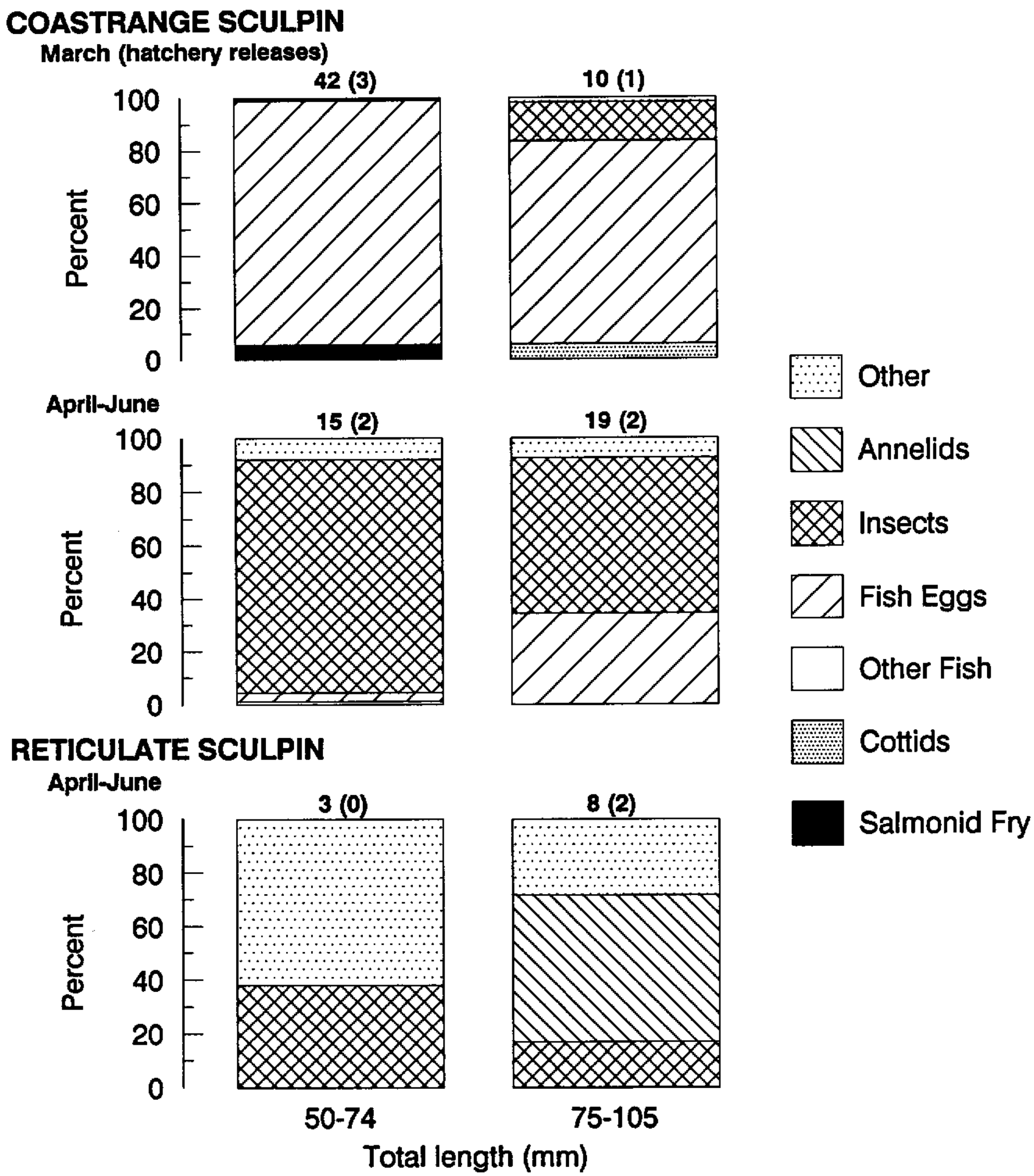


Figure 15.-- Composition (percent by weight) of ingested food for two size categories of coastrange and reticulate sculpin in the lower Cedar River, 1996. Percents were calculated from pooled data. Number of predator stomachs that contained prey items is given above the graph; the number of fish with empty stomachs is in parentheses.

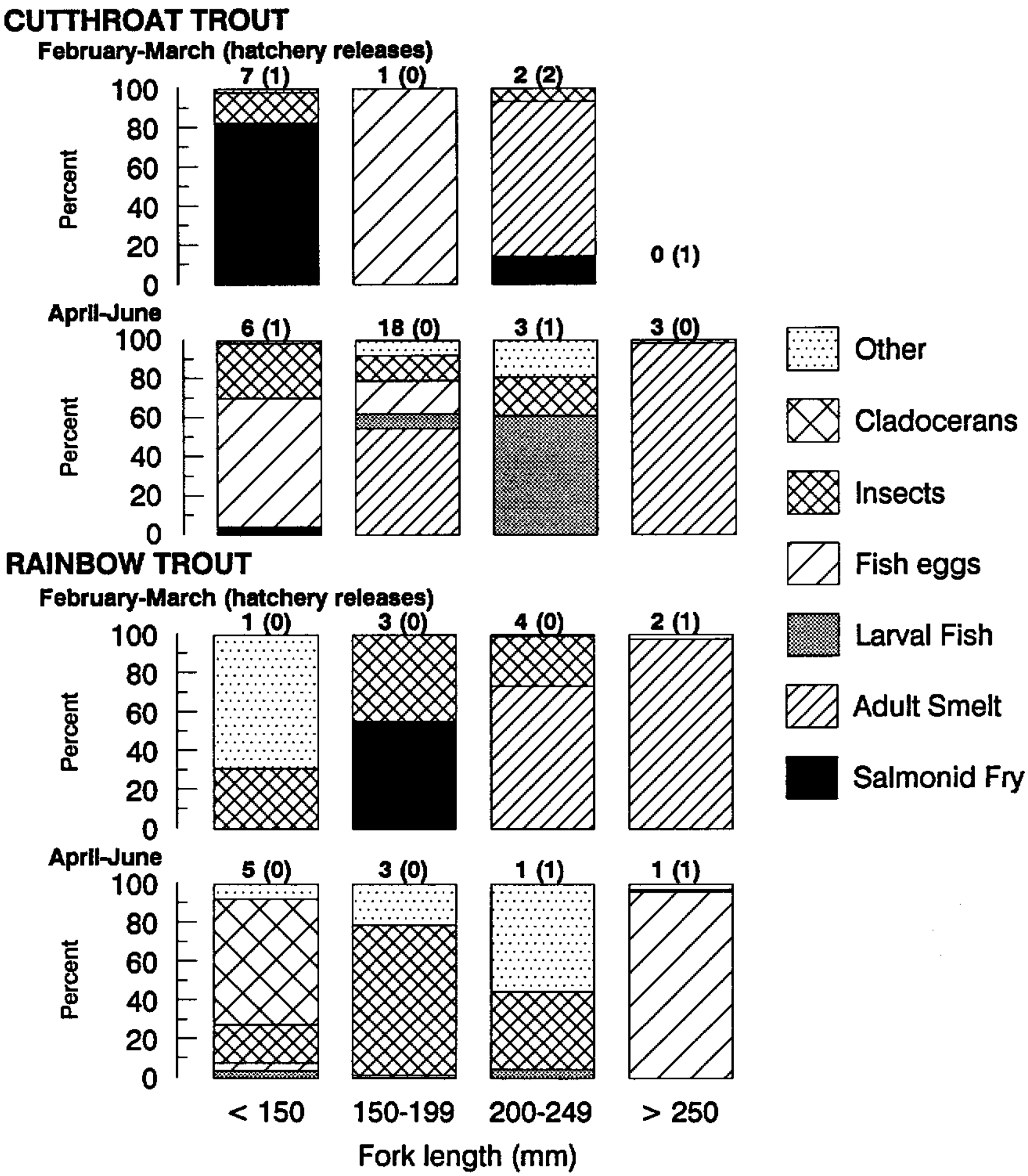


Figure 16.-- Composition (percent by weight) of ingested food for four size categories of cutthroat and rainbow trout in the lower Cedar River, 1996. Percents were calculated from pooled data. Number of predator stomachs that contained prey items is given above the graph; the number of fish with empty stomachs is in parentheses.

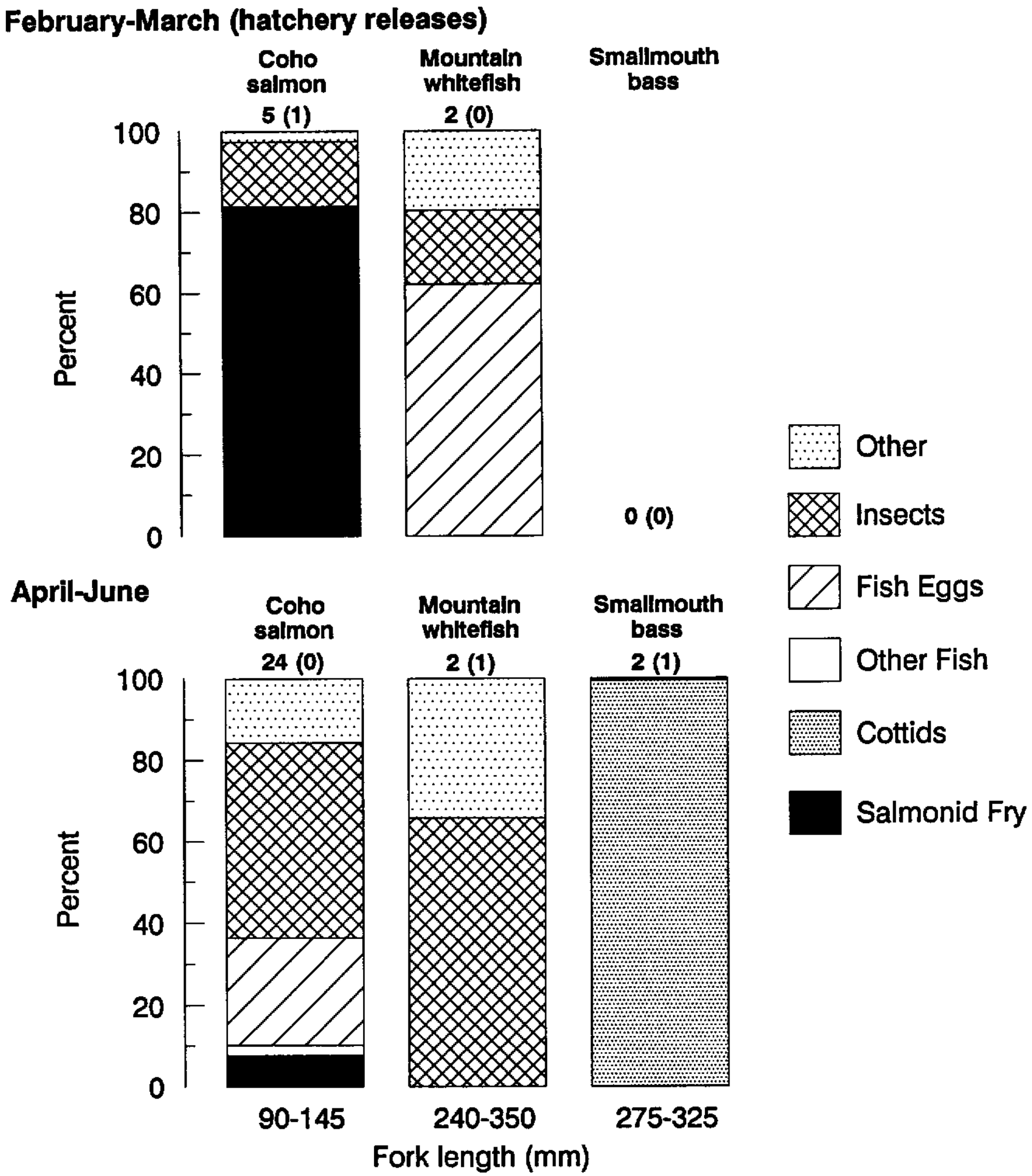


Figure 17.-- Composition (percent by weight) of ingested food of juvenile coho salmon, mountain whitefish, and smallmouth bass in the lower Cedar River, 1996. Percents were calculated from pooled data. Number of predator stomachs that contained prey items is given above the graph; the number of fish with empty stomachs is in parentheses.